ECOLOGICAL STUDIES OF THE BENTHIC FAUNA IN AN ARCTIC ESTUARY

A

THESIS

Presented to the Faculty of the
University of Alaska in Partial Fulfillment
of the Requirements
for the Degree of
MASTER OF SCIENCE

By

JAMES JOHN CRANE, B. S.

Fairbanks, Alaska

August 1974

ECOLOGICAL STUDIES OF THE BENTHIC

FAUNA IN AN ARCTIC ESTUARY

APPROVED:

Howard M. Feder

Robert T. Cooney

Chairman

Department Head

APPROVED: DATE:

Dean of the College of Mathematics,
Physical Sciences and Engineering

Vice President for Research and
Advanced Study

ABSTRACT

Distributions and abundances of benthic fauna are described for the nearshore Beaufort Sea adjacent to the mouth of the Colville River. Harrison Bay, Simpson Lagoon, and the shallow waters seaward of the barrier islands were sampled with a small bottom trawl and grab during the late summer of 1971. This survey was part of a larger effort by the University of Alaska to obtain baseline information prior to oil exploration and development.

Forty-seven species, dominated numerically by Crustacea, Mollusca, and Polychaeta were studied from a collection of 86 samples. The isopod, *Mesidotea entomon*, and the mysid, *Mysis oculata* were common to all areas examined. Standing stocks of both were significantly higher ($P<0.05$) seaward of the lagoons. The spatial distribution of infauna clearly reflected the influence of the seasonal zone of bottom-fast ice.

The biology, life history, and production of selected species are described, and relationships between environmental factors discussed as related to understanding this nearshore community.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

I am deeply indebted to Dr. R. T. Cooney, my advisor, for his professional counsel, encouragement, and many hours spent helping me solve the difficult problems of Arctic research. I also thank the other members of my committee, Drs. C. P. McRoy, H. Feder, W. Reeburgh, and P. Kinney for their suggestions and critical review of this thesis. I particularly acknowledge Dr. McRoy for his assistance on the initial phase of this project and his prompt and thorough evaluation of numerous draft copies of this thesis.

I also thank NARL at Barrow for logistical support and use of the RV Natchik, the ITT Corporation for use of their faciltiies, and the men of POW II DEWLINE STATION for their aid and cheerful acceptance of my presence underfoot in their station. A special thanks is due Mr. George Mueller for his many fine suggestions, encouragement, friendship, and permission to fully use the Museum Invertebrate Collections' space and equipment; I am also grateful for my taxonomic training by Mr. Mueller. Figure preparation was performed by the Institute of Arctic Biology Drafting Section. Species thanks are also due Mrs. Rosemary Hobson for her help in "debugging" my computer program. I also acknowledge the preparation of this manuscript for publication by Mrs. Linda Carver, Mr. C. R. Grunder, and the IMS secretaries.

The project was supported by NSF Sea Grant B83, NOAA Sea Grant 36109, EPA Contract 16100 EOM, the State of Alaska, and the Prudhoe Bay Environmental Subcommittee.

Chapter 1

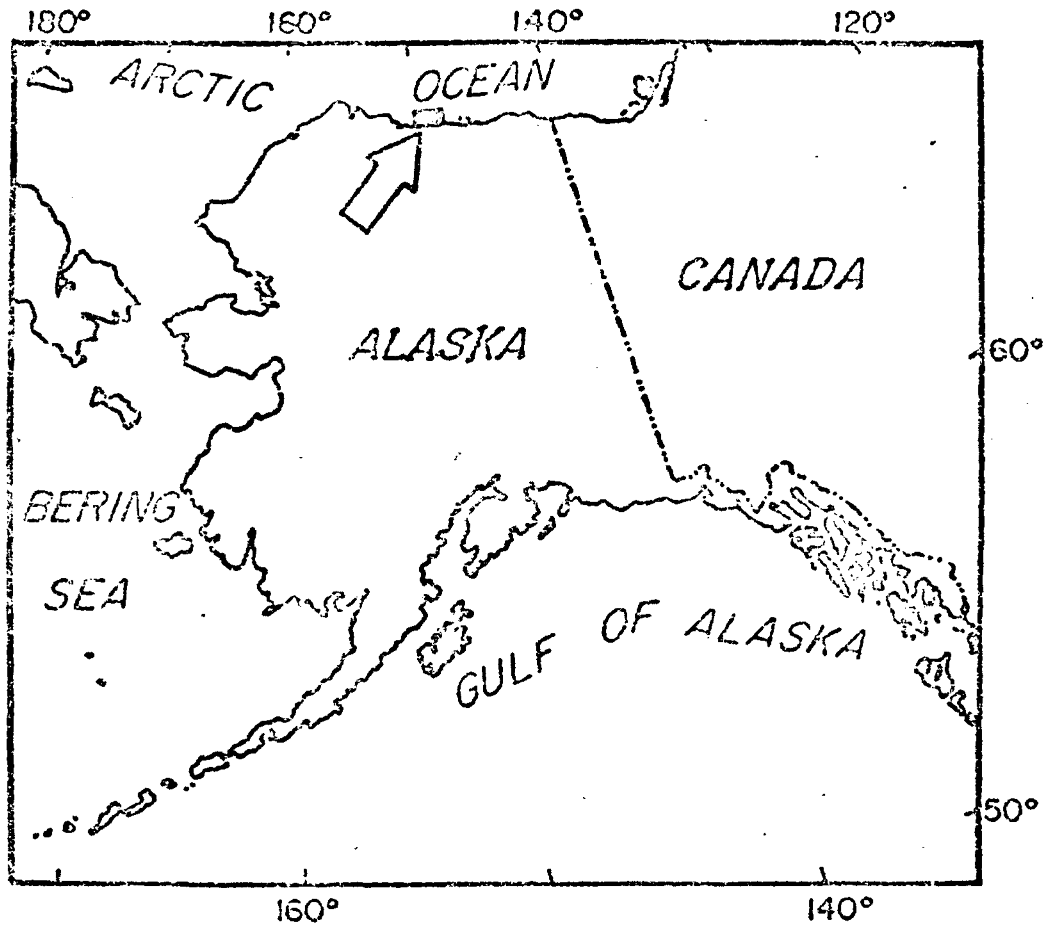
INTRODUCTION

1.1 Purpose of the Investigation

In 1970 the Institute of Marine Science, University of Alaska, began a baseline study of a portion of the Alaskan Arctic environment adjacent to the Colville River (Fig. 1). This work was undertaken because the shallow lagoon, barrier-island nearshore marine systems, the tundra lakes, and the rivers of this region are almost entirely undescribed. Oil exploration and development in the region is expected to change the environment. In order to evaluate the effects of change, knowledge of the present relatively unchanged environment must be obtained as the basis for comparison (Kinney *et al.*, 1971).

The objective of this research was to investigate the benthic fauna of the estuarine component of the environment. In this investigation, three areas were studied: 1) Simpson Lagoon, a shallow nearshore lagoon; 2) the Beaufort Sea, an offshore area seaward of the lagoonal barrier islands; and 3) Harrison Bay, a large shallow bay. A general survey of the benthic invertebrate fauna was made using a small trawl and bottom grab. Extensive ecological and biological data were gathered for selected dominant species.

Fig. 1. Map of Alaska showing the study area in relation to the Alaskan coast.


180°
160°
140°
120°
ARCTIC
OCEAN
CANADA
ALASKA
60°
BERING
SEA
GULF OF ALASKA
50°
160°
140°

1.2 Literature Review

Although comprehensive benthic invertebrate surveys have been conducted in certain arctic nearshore regions of the world (Greenland, northeastern Canada, Scandinavia), almost no work has been carried on in the nearshore lagoons of Arctic Alaska (MacGinitie, 1955). In contrast, the Russians have extensively surveyed their Arctic coastal lagoons in Siberia (Zenkevitch, 1963).

In Alaska most studies have been carried out south of the Bering Strait (MacGinitie, 1955). Work originating north of the Strait generally has been associated with the Naval Arctic Research Laboratory at Point Barrow, Alaska; consequently, most of these studies are of the Barrow region. One of the most complete surveys of this portion of the Arctic coast was made by MacGinitie from 1948-1950 using dredges, nets, and beachcombing. From the material collected, a fairly complete picture of the species present in the region was obtained. Before 1948, a few ships and expeditions, the Yukon, a USCGS schooner under Dall (1880), the Corwin under Healy (1884-1885), and the Canadian Arctic Expedition (1913-1918), collected some of the marine fauna in the Barrow region (MacGinitie, 1955). Taxonomic studies of the local molluscs and polychaetes were reported by MacGinitie (1959) and Pettibone (1954). A limited study of mysids was conducted near Point Barrow in 1961 (Holmquist, 1963).

In 1953, the U. S. Coast and Geodetic Survey aboard the LCM Red sampled 18 stations of the nearshore Arctic coast from Barter Island to Barrow collecting by hand, basket dredges, and otter trawls (Fig. 2). The faunal composition of this material was described as benthic Tanaidacea and Isopoda (Menzies and Mohr, 1963), Cumacea (Given, 1965), Pelecypoda (Hulsemann, 1962), and Bryozoa (Hulsemann and Soule, 1962).

In 1959, a nearshore area from Cape Seppings to Point Hope on the northwest coast of Alaska was examined using dredges and otter trawls (Fig. 2). A species checklist emerged from this investigation (Sparks and Pereyra, 1966).

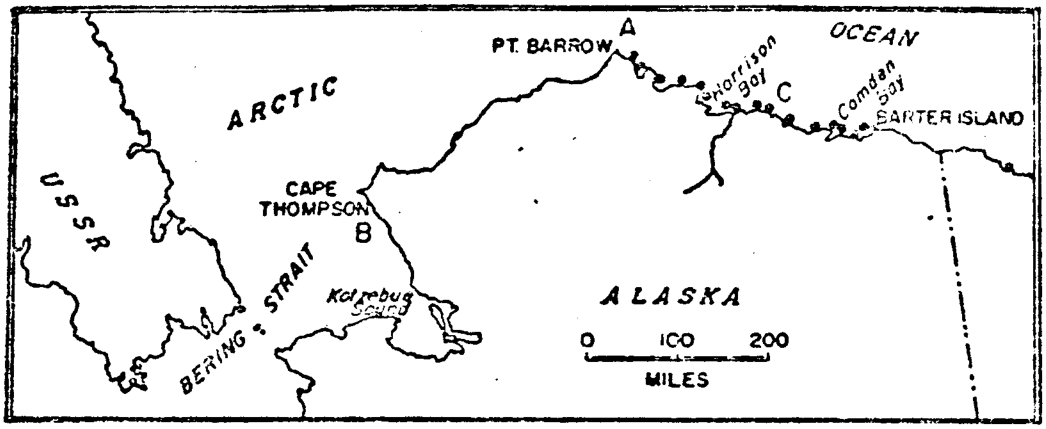
In 1970, the University of Alaska, supported jointly by the National Sea Grant Program and the Environmental Protection Agency began an investigation of the Simpson Lagoon, Colville River Delta area (Kinney *et al.*, 1971). My study, an extension of the University's original effort was designed to quantitatively evaluate the status of the nearshore benthic fauna in the lagoons at the mouth of the Colville River and outside the barrier islands. To my knowledge, no investigation of this type has yet been made on the Alaskan Arctic nearshore benthos.

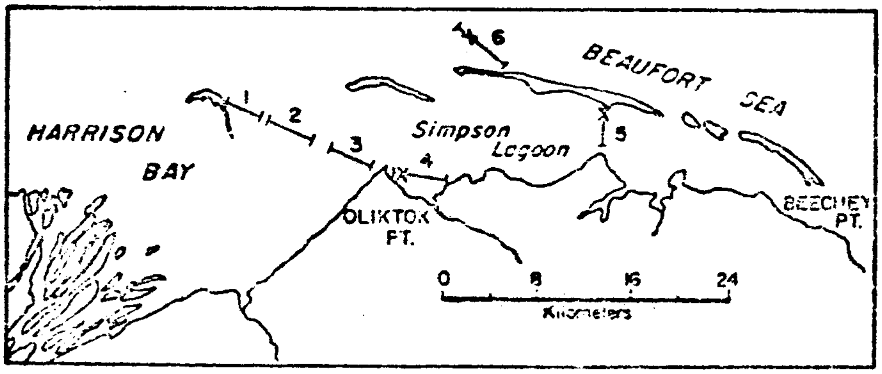
Fig. 2. Map of Arctic Alaska showing the locations

of previous Arctic Alaskan studies of the benthos

Upper: Early studies of the Arctic coast by MacGinitie (A), Sparks and Pereya (B), and the LCM Red Expedition (C).

Lower: Recent studies of the Colville River Delta estuarine benthos.


PT. BARROW
A
OCEAN
ARCTIC
Harrison Bay
C
Camden Bay
BARTER ISLAND
USSR
CAPE THOMPSON
B
BERING STRAIT
Kotzebue Sound
ALASKA
0 100 200
MILES


6
BEAUFORT SEA
1
2
3
4
5
HARRISON BAY
Simpson Lagoon
OLIKTOK PT.
BEECHEY PT.
0 8 16 24
Kilometers

Chapter 2

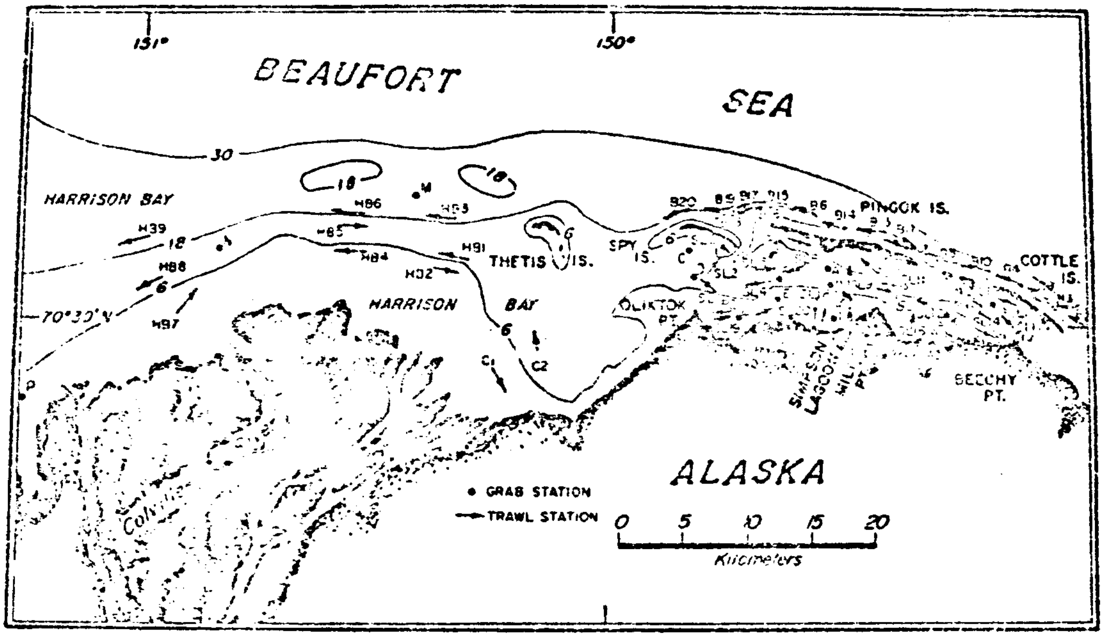
DESCRIPTION OF RESEARCH AREA

The research area, located along 90 km of the northernmost coast of the U.S., is characterized by a high Arctic climate with high winds and fog, and shallow turbid lagoons. The severity of the environment is a factor limiting the effectiveness of most collecting efforts.

2.1 Topography

Three areas were sampled in this study (Fig. 3). Harrison Bay, a shallow, bar-filled bay, is approximately 91 km in width and 32 km long. The shoreward margin of this bay is formed by the seaward extension of the Colville River Delta, a maze of channels and mud or sand bars. The bay is the terminus of the Colville River which flows northward from the Brooks Range through the Arctic coastal plain in a drainage basin of 63,900 km^2 (MacGinitie, 1955). Simpson Lagoon to the east of Harrison Bay, is a shallow body of water separated from the Beaufort Sea by a series of barrier islands, some of which are gravel while others are tundra covered. This lagoon is 29 km long, and its width varies from 6.5 km in the west to about 3.2 km in the east. The barrier islands rise to 11 m above sea level, and range between 61 and 910 m in width. The third study area was the margin of the Beaufort Sea offshore from the barrier islands at depths from 4.6 to 7.6 m.

Fig. 3. Stations occupied in August 1971. Arrows mark benthic trawl stations, dots indicate grab stations.



151°
150°
BEAUFORT
SEA
30
18
HARRISON BAY
H39
H88
H97
70°30'N
H86
H85
H84
H91
THETIS IS.
SPY IS.
HARRISON
BAY
C1
C2
SL2
B20
B6
PINGOK IS.
COTTLE IS.
OLIKTOK PT.
BEECHY PT.
ALASKA
Colville
• GRAB STATION
TRAWL STATION
0 5 10 15 20
Kilometers

2.2 Sedimentology

Detailed sedimentology of the study area is not available at this time, although data are presently being compiled by the Institute of Marine Science of the University of Alaska (Tucker, personal communication).

Some sediments were sampled in Simpson Lagoon and Harrison Bay where grab stations were occupied. Particle size analysis showed sandy muds, muddy sands, sandy gravels, sands, and gravels as the major sediment types.

Harrison Bay sediments are characterized by sandy muds, although muddy sands and sands are also found in the bay (U.S. Department of Commerce, Coast and Geodetic Survey, Charts 9469 and 9470). Detrital organic material, a peat washed in from the margin of the bay, forms mounds on the bottom.

Simpson Lagoon has sandy muds and muddy sands in the areas deeper than about 1 m (Tucker, personal communication). Nearshore and near the barrier islands, sandy gravels, gravels, and sands occur. Simpson Lagoon also contains tundra peat and ice-rafted erratics.

The area offshore is relatively undescribed, although it appears that the sediments range from gravels and sands close to shore, to sandy muds further seaward (U.S. Department of Commerce, Coast and Geodetic Survey, Chart 9471).

2.3 Hydrography

Two major seasons are observed along the Arctic coast: 1) the ice-free season, lasting from July to September; and 2) the ice-covered season prevailing through the remainder of the year. Freeze-up of the Colville River and the surrounding region begins in September. After the river ice reaches maximum thickness, the freshwater flow is cut off completely until the thaw begins in the late spring or early summer.

Surface water tempertures in the ice-free season range from 3°C to 12°C; near the bottom the water is characteristically cooler, 0.83°C to 7.0°C. In the ice-covered season, water temperture under the ice may be as low as -1.7°C. (Schell, unpublished data, 1969; Dygas _et al._, 1972).

Salinities vary greatly in the Colville region throughout the year (Kinney _et al._, 1972; Schell and Hall, 1972). Following ice cover, the salinity of the water in Harrison Bay increases from about 27°/₀₀ in September to 32°/₀₀ later in the fall and winter. This increase is related to the loss of freshwater from the Colville River, the concentration of salts which occurs when sea water is frozen, and exchange with the Beaufort Sea water exhibiting a salinity of 30-34°/₀₀.

In contrast, salinities in Simpson Lagoon are about 27°/₀₀ in September at the onset of freezing, and increase in concentration to 66°/₀₀ during maximum ice thickness. Water movement in this lagoon is restricted by the barrier islands and by formation of bottom-fast sea ice sealing off the shallow channels that connect the lagoon with the waters offshore. With maximum ice (about 2 m thick) the extremely high salinity water in Simpson Lagoon is completely isolated from Harrison Bay and the Beaufort Sea. Since the mean depth of the lagoon is only about 2 m, little water remains during this period.

As the ice-free season approaches, there is a pronounced lowering of salinities as melting ice adds low salinity water to the area and the Colville River again contributes large volumes of fresh water. Surface water salinity in Simpson Lagoon then ranges between 10 and 26‰, bottom water from 16 to 23‰. Harrison Bay surface waters are similar to Simpson Lagoon while Harrison Bay bottom water ranges from 18 to 27‰. Surface waters near the outside of the barrier islands range from 20 to 23‰ while bottom water ranges from 22 to 29‰.

Winter and summer dissolved oxygen values for Harrison Bay and Simpson Lagoon vary from 6-16 mg/l, although in the river channels in winter the values may become very low, less than 2 ml/l (Kinney *et al.*, 1971).

The mean lunar tidal range for the Colville area is approximately 15 to 30 cm. However, non-tidal components combined with tidal influences can occasionally cause large sea level changes in the shallow lagoons. Storm surges produced by wind and pressure effects can raise or lower local sea level by 1.5 m over a period of a few days (Kinney *et al.*, 1972). The cumulative effects of these influences are very important where the water depth is shallow (3.3 m or less in Simpson Lagoon) and the slope of the bottom is gradual.

Currents are variable since they are strongly influenced by winds; most are longshore oriented, predominantly to the west. Velocities up to 30 cm/sec, and averaging 17.5 cm/sec have been reported (Kinney et al., 1972).

No measurements of light penetration are available, but visual observations in July and August, 1971, indicate the water to be very turbid probably due to suspended silt and detritus from the river. The bright orange grab sampler generally disappeared from sight at a depth of 1 m.

2.4 Primary Productivity

Studies conducted in the nearshore Colville River estuarine region during the ice-free season of July and August, 1971, show primary production rates of approximately 25 mgC/m^2-day. This figure suggests a low annual production since the active season of no-ice cover lasts only two to three months (Alexander and Billington, 1972).

Chapter 3

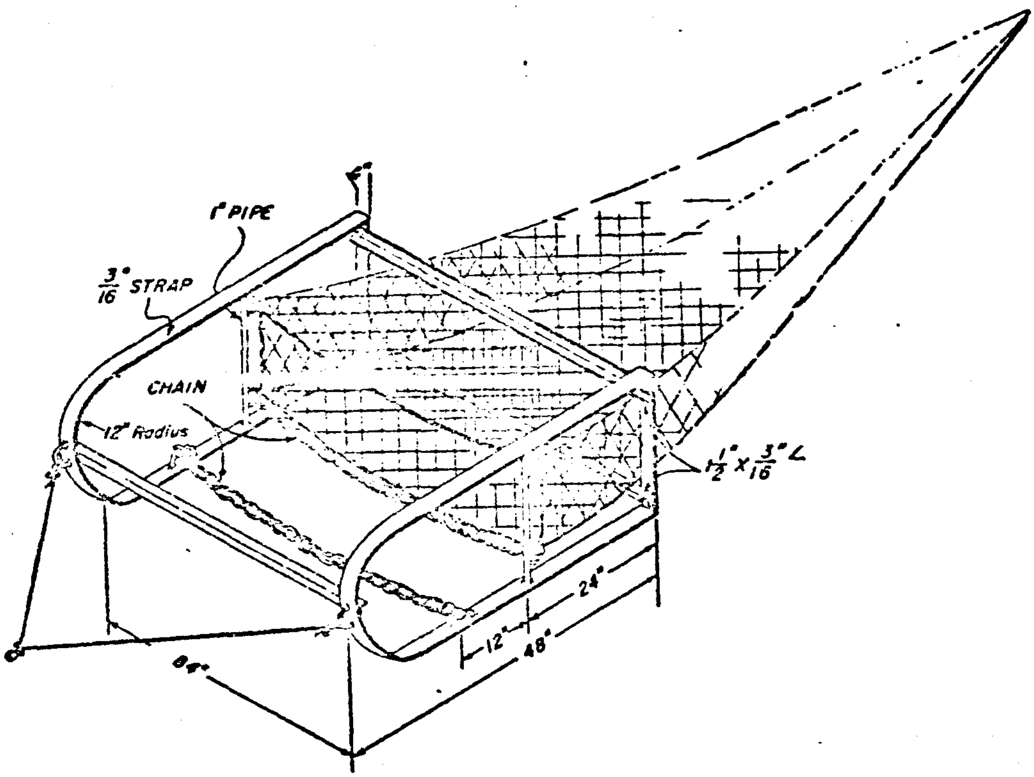
MATERIALS AND METHODS

Most sampling was carried out from the Naval Arctic Research Laboratory's RV *Natchik*, a fishing boat equipped with an A-frame and two power winches. Some supplementary samples were taken from a skiff.

3.1 Equipment

The shallow waters of the Colville region restrict sampling to gear that is small and light enough to be handled easily from a small boat. Epifauna was collected using a 2-m benthic trawl (Fig. 4). The trawl consisted of two steel strap runners held together by three 2-m angle-iron sections. A knotless nylon net with 2.8-mm mesh was attached to eyelets on the frame forming an opening approximately 2 x 0.5 m. The lower and upper edges of the net were tied on the frame to provide a constant opening. A tickler chain was stretched across the runners 15 cm ahead of the lower edge of the net and a chain was tied to the footrope. The height of the lower edge of the net above the bottom was adjustable. A steel cable bridle was attached to eyelets on the front of the runners by shackles.

Fig. 4. The epibenthic trawl


1" PIPE
3"/16 STRAP
CHAIN
12" Radius
1 1/2" x 3/16" ∠
24"
12"
48"
84"

Infauna was collected using a Wildco[1] Ponar bottom grab that sampled an area about .05 m^2. The grab had screen panels to prevent washout and reduce shock waves, and side panels and a lower edge plate that prevented loss of sediment during retrival. A total weight of 28 kg provided good penetration except in coarse sediments.

3.2 Field Sampling Procedures

The number of stations occupied was dependent on availability of boat time, the duration of the ice-free season (mid-July to mid-September), and the daily weather. I chose to sample as many stations as permitted by the above limitations. These included 12 trawl stations in deep Simpson Lagoon (1.8 to 2.8 m), 12 in shallow Simpson Lagoon (<1.8 m), 11 in Harrison Bay, and 18 in the nearshore Beaufort Sea. Three grab stations were occupied in Harrison Bay and 11 in Simpson Lagoon (Fig. 3). Replicate grabs were taken at each station (Appendix I and II).

A tow of five minutes duration at about 1.5 m/sec covering an area of about 900 m^2 was found suitable to capture the organisms known to be in the area, yet did not provide more material than could be adequately handled on the boat. The height of the lower edge of the net above the bottom was adjusted until attached hydroids and shallow burrowing molluscs were collected indicating the trawl was actually fishing the bottom.

---

[1]Wildlife Supply Company, Saginaw, Michigan.

The starting point of a run was first determined within each area using a grid and random number table. The direction of tow was then chosen by selecting direction cards in a similar manner. When the direction chosen was impossible to follow because of hazards, or the tow would terminate outside the study area, new directions were chosen. When the net was overturned by bottom obstacles or some part of the sampling procedure varied, the haul was repeated.

The ratio of tow-cable length to fishing depth was approximately 10:1. A stopwatch was utilized to time cable out, towing and cable retrieval. Following a haul, the sample was placed in labelled plastic bags, preserved in 10% formalin, and sealed. Later onshore solutions were changed and the bags were resealed.

A grid and random number table were used to choose the location of grab stations in Simpson Lagoon (Fig. 3). Initially from the Natchik, the grab was lowered rapidly by a power winch; later in the skiff it was lowered by hand. The material collected was poured into a measuring bucket to determine the volume of sediment taken and then the sample was sieved through a 3-mm screen. Silty-clay sediments and the lack of running water made it impractical to use a smaller mesh. Organisms were preserved in 10% formalin and labelled. Samples for sediments were taken at most stations.

3.3 Laboratory Methods

Organisms from all samples were sorted into taxonomic categories and identified to species whenever possible; a list was compiled for each area. Three numerically dominant animals were chosen for additional study, the isopods *Mesidotea entomon* and *M. sibirica*, and the mysid *Mysis oculata*.

In trawl samples, only *Mesidotea entomon* and *Mysis oculata* were counted. Samples of *Mysis oculata* were reduced to a subsample of 100-200 organisms using a mechanical zooplankton subsampler (Cooney, 1971). Total mysids for each station were estimated by multiplying subsample counts by 2^n where n is equal to the number of half-splits required to produce the final subsample. All organisms in grab samples were counted.

Morphometric measurements consisted of telson length for all *M. entomon* and total length (base of split notch on the middle of the head to the end of the telson) for some representative sizes. The total length (tip of head to end of telson) of all the *M. sibirica* was recorded. For *Mysis oculata*, the total length from the middle of the eyes to the tip of the uropods was measured.

M. entomon were categorized male, female, or juvenile. Males are recognized by an opening in the median pair of papillae on the ventral, posterior segment of the thorax; females have no papillae (Kaestner, 1970). Juveniles were designated as those animals with telson lengths less than 9 mm that could not be sexed. Brood pouches and their contents were also recorded for *M. entomon*.

Formalin dry weights of *Mesidotea entomon* and *Mysis oculata* were measured for some individuals in each size class, and for all organisms in grab samples. Specimens were dried in an oven for a minimum of 16 hours at 60°C or until a constant weight was reached (Lovegrove, 1966).

Carbon analysis of a number of organisms was determined using a Perkin-Elmer Model 240 Elemental Analyzer.[2] Specimens of *M. entomon* and *Mysis oculata* from representative size classes were ground in a mortar, analyzed, and an average carbon content for each species calculated. For comparative purposes seven other local species were also analyzed to determine their average carbon content.

3.4 Statistical Methods

Statistical analyzes were performed to test hypotheses and relationships between variables, and to provide estimates of variability. For trawl data, a one-way analysis of variance (ANOVA) was used to determine if the abundance of organisms was similar at different depths within areas. In cases where these subareas were similar ($P > 0.05$), station counts were combined for further comparisons. After the areas to be compared were determined, another analysis of variance for one-way

---

[2]Perkin-Elmer Company, Norwalk, Connecticut.

design was utilized to test the significance of abundance differences between areas. A computer program using untransformed and base-ten logarithmic transformed data was used for this analysis (Dixon, 1965). This procedure was also used for grab abundance and biomass data except that only untransformed counts were used and only standard deviations derived. Snedecor (1962) explains the use and value of the analysis of variance for testing hypothese and developing confidence limits.

To compare trawl abundance data between areas, geometric means were plotted with confidence limits (*P*=0.05) and ranges for each category of organism. Confidence limits were determined by the equation:

$$CL = \bar{x}_{geo} \; x/\div [\text{antilog} \; (t \sqrt{\frac{MSE}{n}})]$$

Where CL is an upper or lower confidence limit; t is Student's t at *P* = 0.05; MSE is the within cell variance; n is the number of observations. When the geometric mean of one area fell within the confidence limits of another, the two were not considered to be different in terms of average abundance.

The model used for all regression relationships was:

$$Y = a + \beta x$$

Where Y is the dependent variable; a is the intercept on the vertical axis by the line; β is the slope of the line; and x is the independent variable. Regression equations were compared by a test outlined in Lark

(1965). The test compares error variances using the F test and regression coefficients using the t test. When the equations compared were found to be the same, the equations were combined.

Standard deviations were calculated for trawl data, grab data, telson-length vs. total length regression equations, dry weight grab data, dry weight vs. telson length regression equations, and carbon vs. length regression equations.

To determine the distributional patterns of the fauna collected in grabs, a coefficient of dispersion was used (Ellis, 1960). The coefficient is calculated using the equation:

$$CD = \frac{\Sigma\ (x-\bar{x})^2}{\bar{x}\ (n-1)}$$

Where CD is the coefficient of dispersion; x is the number of individuals per grab; $\bar{x}$ is the mean number of individuals per grab; n is the number of grabs. A CD >1 points to aggregations, CD = 1 indicates a random dispersion, and CD <1 points to uniform dispersion of organisms.

3.5 Standing Stock Estimates

Standing stock values for the two dominant species collected by trawling were estimated by the equation:

$$S.S. = CF_x \frac{[\Sigma(N \cdot D)]}{T \cdot A}$$

Where S.S. is the standing stock in mgC/m^2; CF_x is the conversion factor for dry weight to carbon; N is the number of organisms in a size class; D is the average formalin dry weight for an organism in a size class in mg; T is the number of hauls taken in an area; A is the area in m^2 covered by any single five minute haul. For _M. entomon_ N was determined directly. For _Mysis oculata_, the number of animals in each size class was determined from size frequency information and the total number of mysids sampled.

Chapter 4

RESULTS

4.1 The Nearshore Benthos

Forty-seven species were identified from 53 trawl hauls and 33 grab samples taken in three study areas; fifteen species were common to all (Table 1). For trawl samples, Simpson Lagoon and Harrison Bay had 18 species in common, Simpson Lagoon and the nearshore Beaufort Sea shared 19 species, and Harrison Bay and the nearshore Beaufort Sea were characterized by 18 species in common. In the grab samples, three species were common to both Harrison Bay and Simpson Lagoon.

The fauna collected by the trawl was dominated numerically by isopods, amphipods, mysids, and cumaceans; crustaceans were of lesser importance in the grab samples. In the context of this investigation, a species is considered: 1) ubiquitous (U), if it occurs in 67% to 100% of the samples taken within an area; 2) common (C), if it occurs in 34% to 66% of the samples; and 3) rare (R), if it occurs in fewer than 34% of the samples. The isopod *Mesidotea entomon*, the mysid, *Mysis oculata*, and the amphipod, *Acanthostepheia behringiensis*(?), were ubiquitous in all three areas investigated by trawl. The

Table 1. Organisms collected and their occurrence in the study areas, 1971

Category	TRAWL Harrison Bay	TRAWL Beaufort Sea	TRAWL Simpson Lagoon	GRAB Harrison Bay	GRAB Simpson Lagoon
Porifera					
Echinoclathria beringensis	-	R	-	-	-
Hydroidea					
Tubularia indivisa	R	R	U	-	R
Fillellum serpens?	-	R	-	-	-
Grammaria immersa?	-	R	-	-	-
Nemertea					
Species I	-	R	-	-	-
Species II	-	R	-	-	-
Cerebratulus marginatus	-	-	-	-	R
Polychaeta					
Harmothoe imbricata	R	R	-	-	-
H. extenuata	-	C	R	-	-
Sphaerodorium minutum	-	R	R	-	-
Spio filicornis	R	R	-	C	R
Ampharete vega	-	-	-	-	C
Terebellides sttoemi	-	-	-	-	R
Chone duneri	-	-	-	-	R
Bryozoa					
Eucratea loricata	R	R	R	-	-
Priapulida					
Priapulus caudatus	-	R	-	-	C
Mollusca					
Liocyma fluctuosa	R	R	-	-	-
Yoldia arctica	C	R	R	-	R
Axinopsis serricata	R	R	R	-	-
Mya pseudoarenaria	-	R	-	-	-
Cyrtodaria kurriana	R	-	R	-	C
Mytilus edulis	R	-	-	-	-
Cylichna occulta	R	-	R	-	-

Table 1 (cont.)

Category	TRAWL Harrison Bay	TRAWL Beaufort Sea	TRAWL Simpson Lagoon	GRAB Harrison Bay	GRAB Simpson Lagoon
Pycnogonida					
Nymphon grossipes	-	R	R	-	-
Isopoda					
Mesidotea entomon	U	U	U	R	U
M. sibirica	R	C	R	-	-
M. sabini	R	R	-	R	-
Cumacea					
Diastylis sp.	U	C	C	-	R
Amphipoda					
Acanthostepheia behringiensis?	U	U	U	-	-
Pseudalibrotus litoralis?	C	U	C	-	R
Gammaracanthus loricatus	R	C	C	-	-
Gammarus locustus	R	C	C	-	-
Byblis gaimardii?	R	R	R	-	-
Acanthonotozoma inflatum?	-	R	-	-	-
Hyperia medusarum	-	R	-	-	-
Pseudalibrotus sp.	-	R	-	-	-
Weyprechtia pinguis	-	R	R	-	-
Amphipod A	R	-	R	-	-
Amphipod B	R	R	R	-	-
Amphipod C	-	-	R	-	-
Amphipod D	-	-	-	-	C
Amphipod E	-	-	-	R	U
Mysidacea					
Mysis oculata	U	U	U	-	-
Mysis sp.	-	-	R	-	-
Chordata					
Molgula oregonia	-	R	R	-	R
Tunicate sp. I	-	R	-	-	-
Tunicate sp. II	-	-	R	-	-
Total	22	34	26	4	16

amphipod Gammaracanthus loricatus was ubiquitous within two of the three areas while the amphipods Pseudalibrotus litoralis and Gammarus locustus and the cumacean Diastylis sp. were common in two of the three areas trawled. On the basis of occurrence, Mesidotea entomon and Mysis oculata were chosen for additional studies of size, biomass, and distribution. Two additional species of Mesidotea were examined, since, they sometimes were found in the same haul with M. entomon. This consequence led to a closer investigation of these closely related isopods.

Dominate species occurring in grab samples were the polychaetes Spio filicornis and Ampharete vega, the pelecypod Cyrtodaria kurriana, the priapulid Priapulus caudatus, the isopod M. entomon, and an amphipod designated amphipod E. Five of the above species were common in at least one of the two areas investigated while M. entomon was ubiquitous within one of the two areas.

4.2 Abundance

The three major study areas were examined to determine whether they could be divided into subareas on the basis of distribution patterns related to depth. The Beaufort Sea nearshore was treated as a whole since no attempt was made to stratify the sampling outside the barrier islands while Simpson Lagoon and Harrison Bay were subdivided.

Four zones were considered in Harrison Bay: 1) deep water (>6.5 m); 2) intermediate water (1.8 to 6.5 m); 3) shallow water (<1.8m); and 4) a zone close to the river channel where salinities were lower than in the other subareas. Simpson Lagoon was divided into deep water (>1.8m), and shallow water ($\leq$1.8m) (Appendix III and IV).

Catches within subareas for these two locations were compared using an analysis of variance for one-way design (Table 2).

Logarithmically transformed data (Log_{10} X+1) were used since the standard deviations of untransformed observations appeared strongly correlated with arithmetic means. This relationship was not apparent in the transformed observations (Fig. 5). The null hypothesis of no depth effect was accepted ($P>0.05$) for both Mesidotea entomon and Mysis oculata in Harrison Bay, and the data pooled for further analyses. In Simpson Lagoon, a depth effect was significant ($P<0.05$) for juvenile, female, and total Mesidotea entomon, yet not statistically a factor ($P>0.05$) for males and Mysis oculata. These data were not pooled. Following the evaluation of differences within study areas, the four primary study units, Harrison Bay, nearshore Beaufort Sea, deep Simpson Lagoon, and shallow Simpson Lagoon were compared. Significant differences ($P<0.05$) between areas were apparent for all categories (Table 3).

Geometric means, confidence limits ($P=0.05$), and ranges in catch for Mesidotea and Mysis were plotted by location (Fig. 6). Mysis oculata

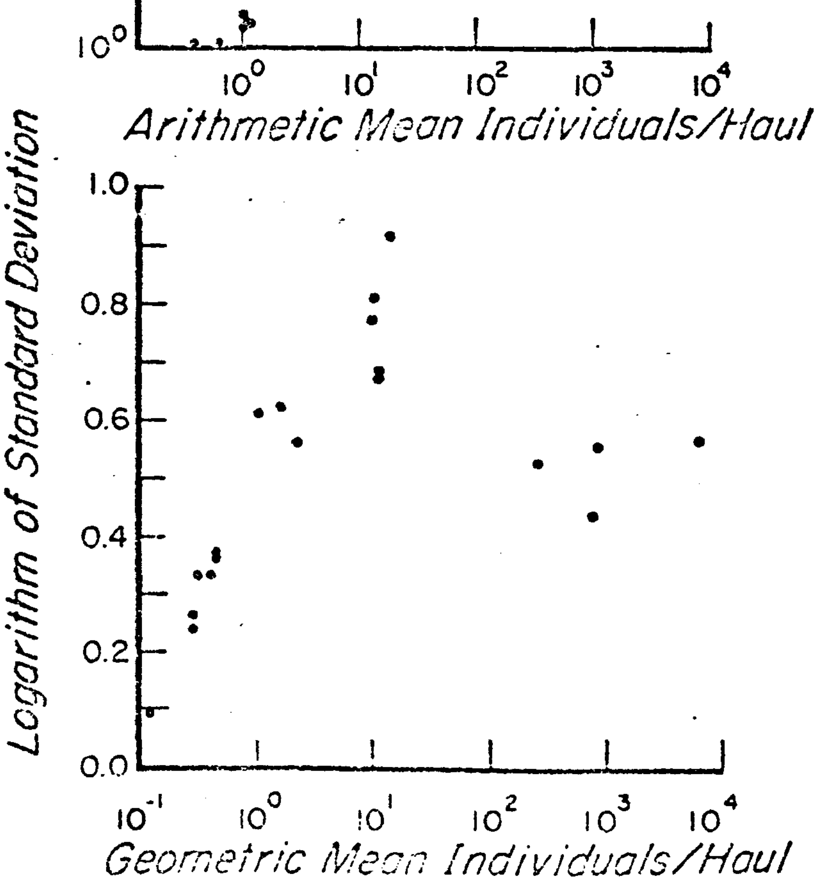
Table 2. The statistical significance of subareas (depths) on the distribution of M. entomon and M. oculata

Location	Source of Variation: Sub-areas[1] F^2	df
Harrison Bay		
Mesidotea entomon		
Juveniles	NS	3, 7
Males	NS	3, 7
Females	NS	3, 7
Total	NS	3, 7
Mysis Oculata	NS	3, 7
Simpson Lagoon		
Mesidotea entomon		
Juveniles	**	1, 22
Males	NS	1, 22
Females	*	1, 22
Total	**	1, 22
Mysis oculata	NS	1, 22

[1] H_o: subarea effect = 0

[2] NS = $P>0.05$; * = $P<0.05$; ** = $P<0.01$

Fig. 5. The relationship between abundance estimates and standard deviations for arithmetic and logarithmically transformed observations.



10^0
10^0 10^1 10^2 10^3 10^4
Arithmetic Mean Individuals/Haul
Logarithm of Standard Deviation
1.0
0.8
0.6
0.4
0.2
0.0
10^{-1} 10^0 10^1 10^2 10^3 10^4
Geometric Mean Individuals/Haul

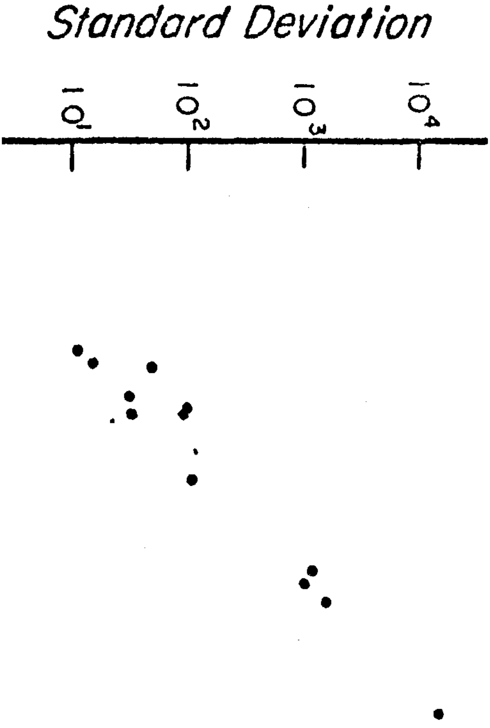

Standard Deviation
10^1
10^2
10^3
10^4

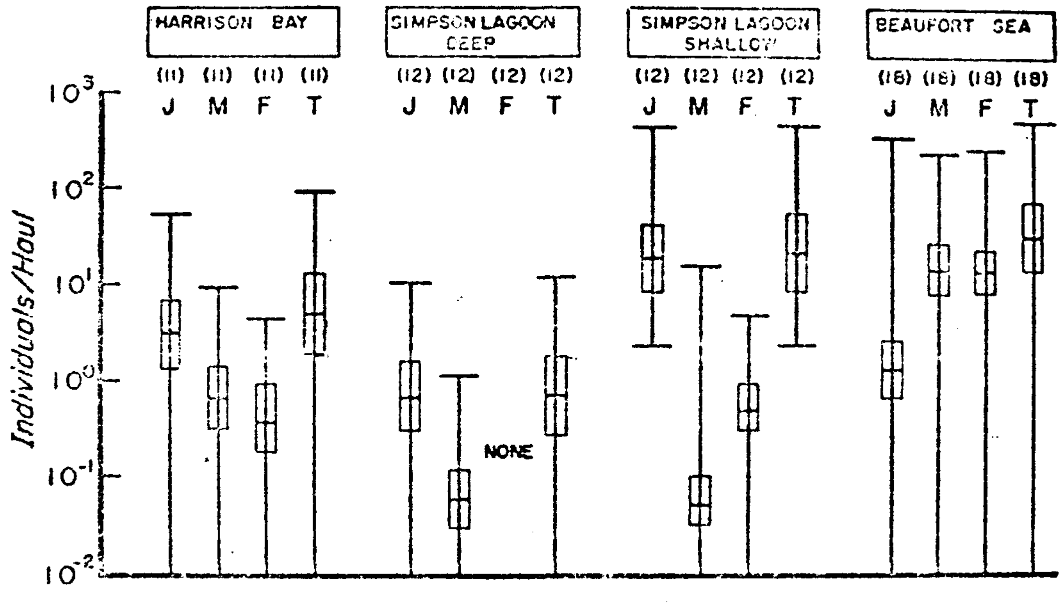
Table 3. The statistical significance of differences in catch between areas for *Mesidotea entomon* and *Mysis oculata*

Categories	Source of Variation	
	Areas[1]	
	F^2	df
Mesidotea entomon		
Juveniles	**	3, 49
Males	**	3, 49
Females	**	3, 49
Total	**	3, 49
Mysis oculata	**	3, 49

[1] H_o: Area effect = 0

[2] NS = $P>0.05$; * = $P<0.05$; ** = $P<0.01$

Fig. 6. Abundance of juvenile (J), male (M), female (F), and total (T) *Mesidotea entomon* in four study areas, August 1971. Geometric means, ranges, and 95% confidence intervals are depicted. The lower limits of ranges are zero unless otherwise indicated.



HARRISON BAY
SIMPSON LAGOON DEEP
SIMPSON LAGOON SHALLOW
BEAUFORT SEA
(11) (11) (11) (11)
(12) (12) (12) (12)
(12) (12) (12) (12)
(18) (18) (18) (18)
J M F T
NONE
Individuals/Haul
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}

was equally abundant in Harrison Bay and shallow Simpson Lagoon, and also found in similar abundance in deep and shallow Simpson Lagoon (Fig. 7). For juvenile *Mesidotea entomon*, the nearshore Beaufort Sea and deep Simpson Lagoon were similar, for males, deep Simpson Lagoon and shallow Simpson Lagoon were the same, and for females, shallow Simpson Lagoon and Harrison Bay did not differ. The abundance of total *M. entomon* was similar in shallow Simpson Lagoon and the nearshore Beaufort Sea.

Mysis oculata, and *Mesidotea entomon* males and females, were much more abundant outside the barrier islands than in either Harrison Bay or Simpson Lagoon. Juvenile *M. entomon* were sampled in equal abundance both in the lagoon and outside of the islands.

Abundance of organisms collected by grab sampling was also determined (Table 4). For deep Simpson Lagoon the average number of total organisms was 313 $\pm$ 230 ind/m^2, for shallow Simpson Lagoon 28 $\pm$ 29 ind/m^2, and for Harrison Bay 22 $\pm$ 33 ind/m^2. The null hypothesis of no area effect (P = 0.05) was rejected when all three areas were compared, when deep Simpson Lagoon and Harrison Bay were compared, and when deep Simpson Lagoon and shallow Simpson Lagoon were compared. The hypothesis was accepted when shallow Simpson Lagoon and Harrison Bay were tested (Table 5). The pelecypod, *Crytodaria kurriana* with 112 $\pm$ 167 ind/m^2, the polychaete *Ampharete vega* with 101 $\pm$ 105 ind/m^2, and two species of amphipods (combined) with 51 $\pm$ 87 ind/m^2 were the most abundant

Fig. 7. Abundance of *Mysis oculata* in four study areas during August 1971. Data presented as in Fig. 6.

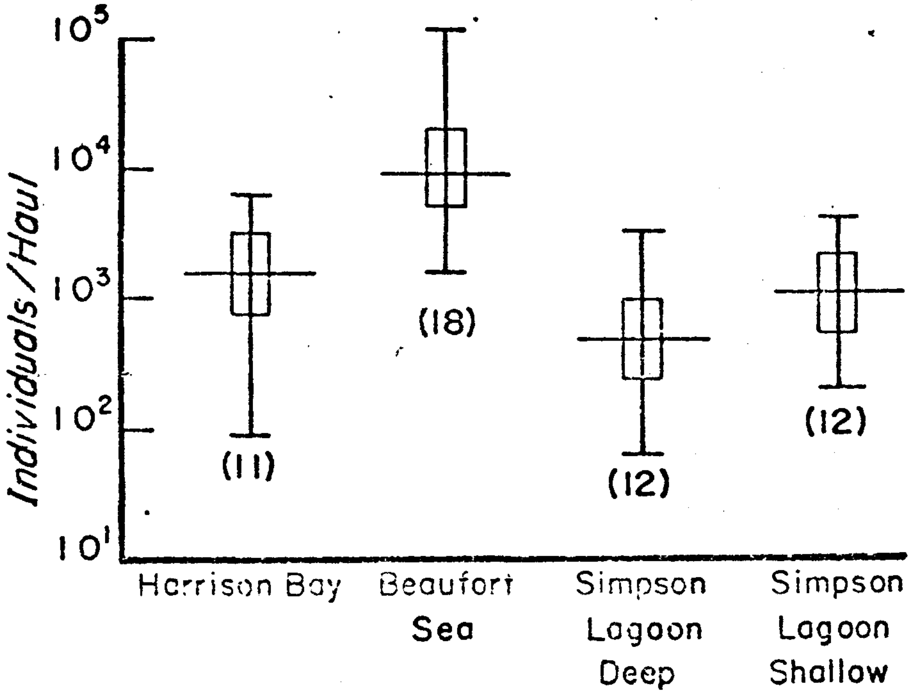

Individuals/Haul
10^5
10^4
10^3
10^2
10^1
(11)
(18)
(12)
(12)
Harrison Bay
Beaufort Sea
Simpson Lagoon Deep
Simpson Lagoon Shallow

Table 4. The distribution of abundance and biomass (dry weight) of organisms taken in grab samples, August, 1971

Species	Harrison Bay no/m^2	Harrison Bay g/m^2	Simpson Lagoon Deep no/m^2	Simpson Lagoon Deep g/m^2	Simpson Lagoon Shallow no/m^2	Simpson Lagoon Shallow g/m^2
Tubularia indivisa,			4±17	.10±.48		
Cerebratulus marginatus			0±4	.04±.17		
Ampharete-vega			101±105	.19±.17		
Terebellides stroemii			0±4	.02±.10		
Spio filicornis	6±14	.03±.00	1±5	.01±.00		
Chone duneri			3±17	.02±.10		
Priapulus caudatus			11±18	.21±.36		
Cyrtodaria kurriana			112±167	9.61±13.69		
Yoldia arctica			7±20	.66±2.04		
Mesidotea entomon	2±7	.09±.28	6±11	.08±.24	18±19	.44±.43
Mesidotea sabini	2±7	.32±.95				
Diastylis sp.			2±9	.00±.00		
Gammaracanthus loricatus			0±4	.02±.10		
Pseudalibrotus litoralis			1±5	.00±.00		
Amphipod X			35±65	.10±.20		
Amphipod Z	11±33	.03±.00	16±22	.04±.00	10±14	.02±.00
Mogula oregonia						
Total	22±33	.48±.94	313±230	11.74±13.58	28±29	.46±.44

Table 5. The statistical significance of areas on the distribution of abundance and biomass of organisms taken in grab sampling.

Location	Source of Variation: Subareas[1] F[2]	df
Harrison Bay, Shallow Simpson Lagoon, Deep Simpson Lagoon		
Total organisms	**	2, 38
Total biomass		
Harrison Bay, Shallow Simpson Lagoon		
Total organisms	NS	17, 1
Total biomass	NS	17, 1
Harrison Bay, Deep Simpson Lagoon		
Total organisms	**	1, 29
Total biomass		1, 29
Deep Simpson Lagoon, Shallow Simpson Lagoon		
Total organisms	**	1, 30
Total biomass	**	1, 30

[1] H_o: Area effect = 0

[2] NS = P>0.05; * = P<0.05; ** = P<0.01

species in Simpson Lagoon Deep. No infauna was collected in Simpson Lagoon Shallow and only one organism, a tube polychaete *Spio filicorms*, was collected in Harrison Bay.

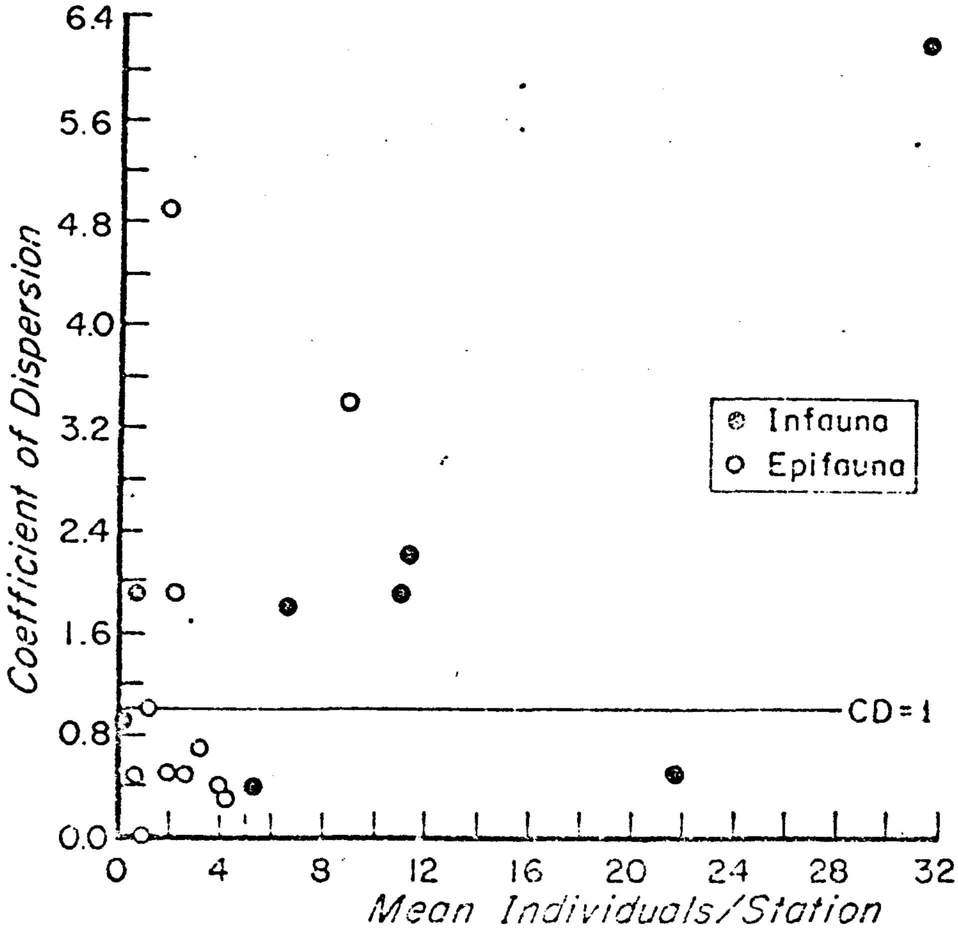
A distributional index, the coefficient of dispersion, was used to investigate whether organisms collected by grab were aggregated (Fig. 8). A coefficient greater than unity points to aggregation of the organisms. Infaunal species exhibited this characteristic while the epifaunal organisms appeared to be more dispersed.

4.3 Size Classes

Length-frequency plots were made for a collection of *M. entomon* taken in August, 1970 (Stoker, unpublished data) in Harrison Bay, Simpson Lagoon, and nearshore Beaufort Sea (Fig. 9). A similar plot was drawn for the *M. entomon* sampled in the same areas in August, 1971 (Fig. 10, Appendix V). The 1970 juveniles are not comparable with the 1971 juveniles because a larger mesh otter trawl was used in the first survey. The Simpson Lagoon information is limited by the small numbers of isopods collected in 1970. Harrison Bay and Beaufort Sea males and females seem to exhibit similar size distributions both years. Males in all areas reach much longer lengths than the females.

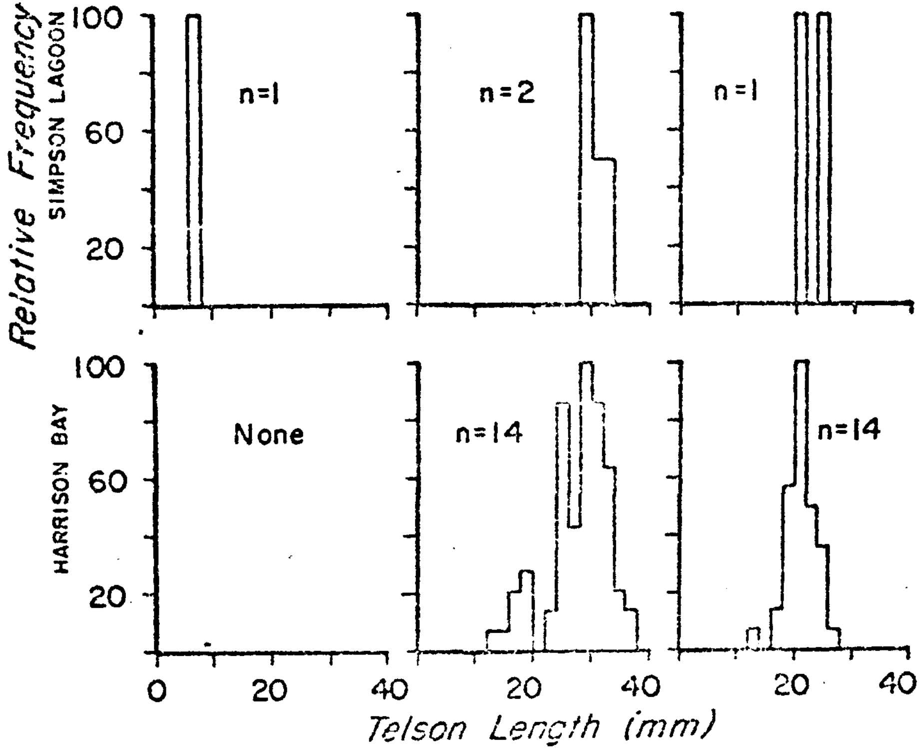
Length-frequency distributions were plotted for all *M. sibirica* sampled in 1971 (Fig. 11) and *Mysis oculata* (Fig. 12, Appendix VI). Two large female *M. sibirica* (58-60mm total length) were collected as

Fig. 8. Relationship between the coefficient of dispersion and the average number of individuals per sample.



Coefficient of Dispersion
6.4
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0.0
0
4
8
12
16
20
24
28
32
Mean Individuals/Station
Infauna
Epifauna
CD = 1

Fig. 9. Distribution of size classes for *M. entomon* in the study areas August 1970. N is the number of organisms in the largest size class.


Relative Frequency
SIMPSON LAGOON
HARRISON BAY
100
60
20
n=1
n=2
n=1
None
n=14
n=14
0
20
40
Telson Length (mm)

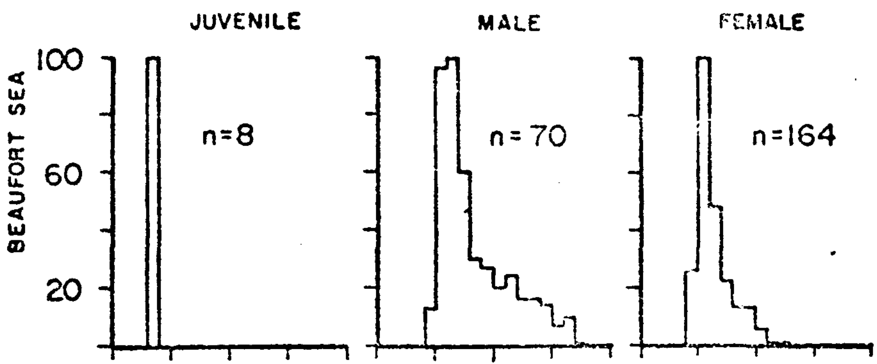

JUVENILE
MALE
FEMALE
BEAUFORT SEA
100
60
20
n=8
n=70
n=164

Fig. 10. Distribution of size classes for _M. entomon_ in the study areas August 1971. N is the number of organisms in the largest size class.

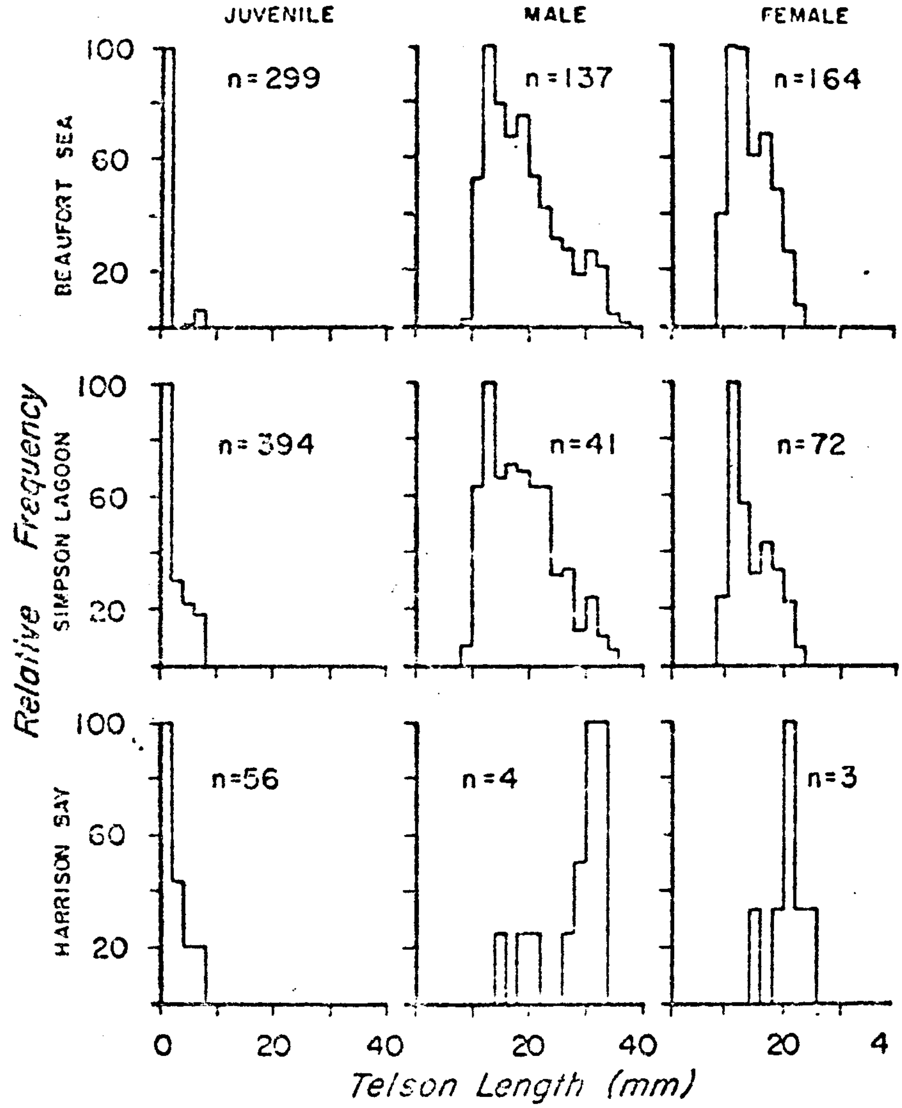

JUVENILE
MALE
FEMALE
BEAUFORT SEA
SIMPSON LAGOON
HARRISON BAY
n=299
n=137
n=164
n=394
n=41
n=72
n=56
n=4
n=3
Relative Frequency
100
60
20
0
20
40
Telson Length (mm)

Fig. 11. Distribution of _Mesidotea_ _sibirica_ size classes in study areas, August 1971.

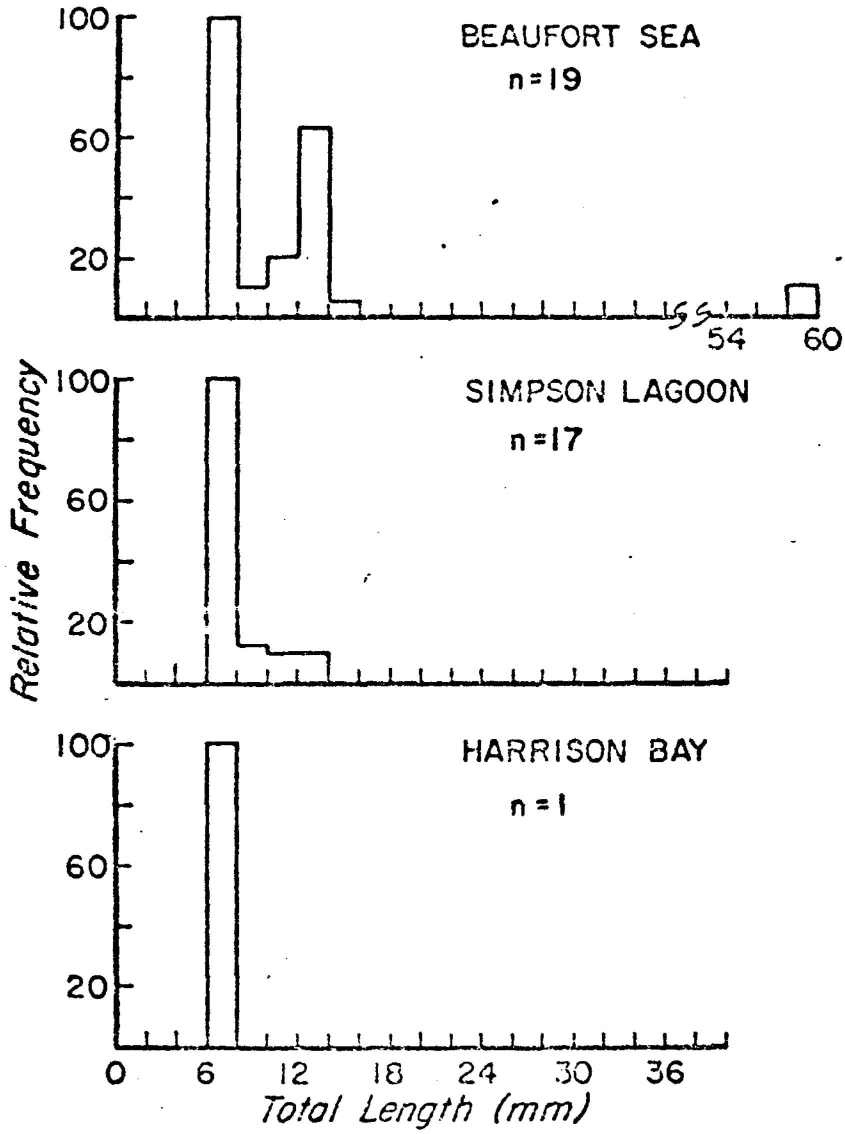
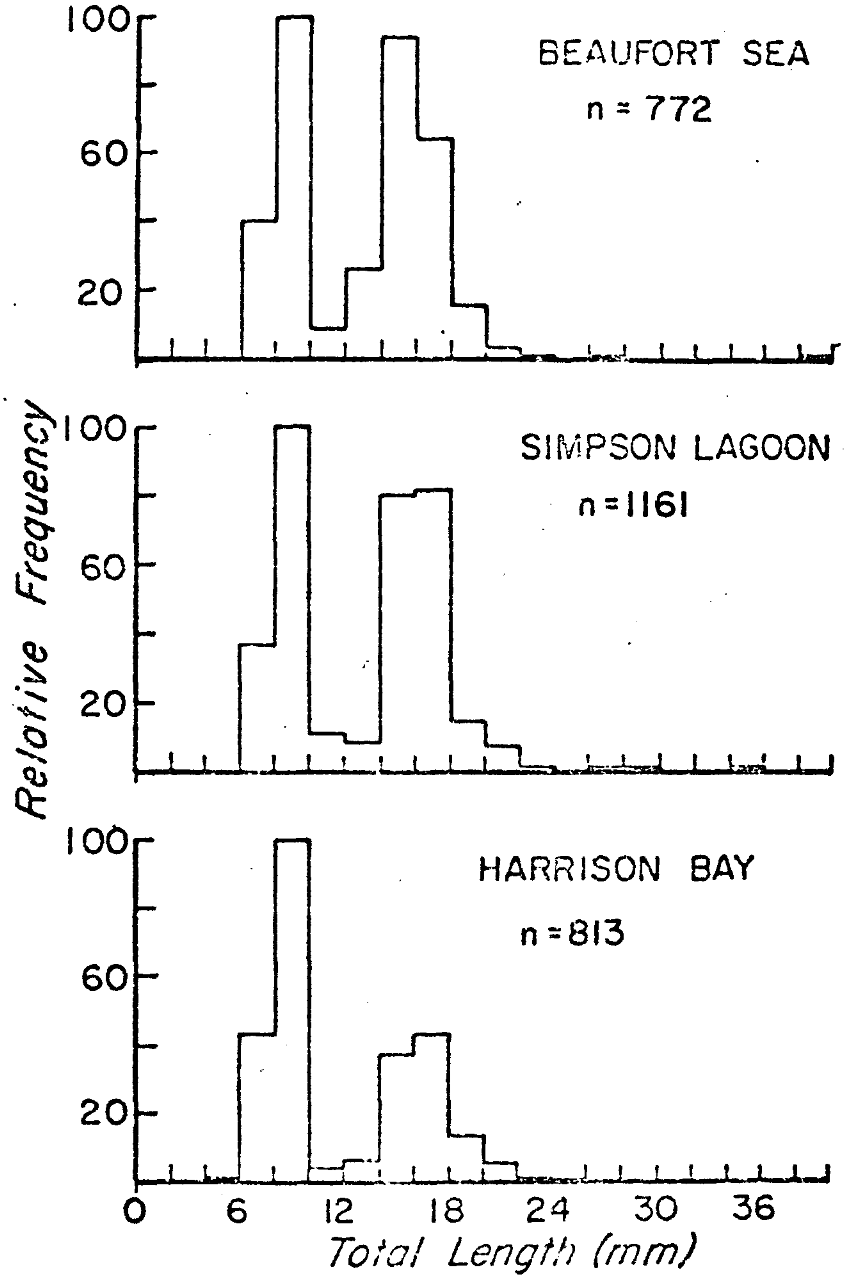

BEAUFORT SEA
n=19
SIMPSON LAGOON
n=17
HARRISON BAY
n=1
Relative Frequency
100
60
20
0
6
12
18
24
30
36
54
60
Total Length (mm)

Fig. 12. Distribution of *Mysis oculata* size classes in study areas, August 1971.



BEAUFORT SEA
n = 772
SIMPSON LAGOON
n = 1161
HARRISON BAY
n = 813
Relative Frequency
100
60
20
0
6
12
18
24
30
36
Total Length (mm)

well as 40-50 smaller size (16 mm). An intermediate size class appears not to be in the area or at least was not collected.

All three species appear to have three size classes or modes in which most of the organisms occur (Fig. 13). For M. entomon, the first mode (0-2 mm) represents recently release juveniles, the second, the one-year-olds, and the third (very low), the two-year-olds. Three soze classes are vaguely seen in the distribution of M. sibirica although some sizes may be missing which could change the position of the modes. Mysis oculata is characterized by animals of three distinct sizes with the two-year-olds again in very small numbers.

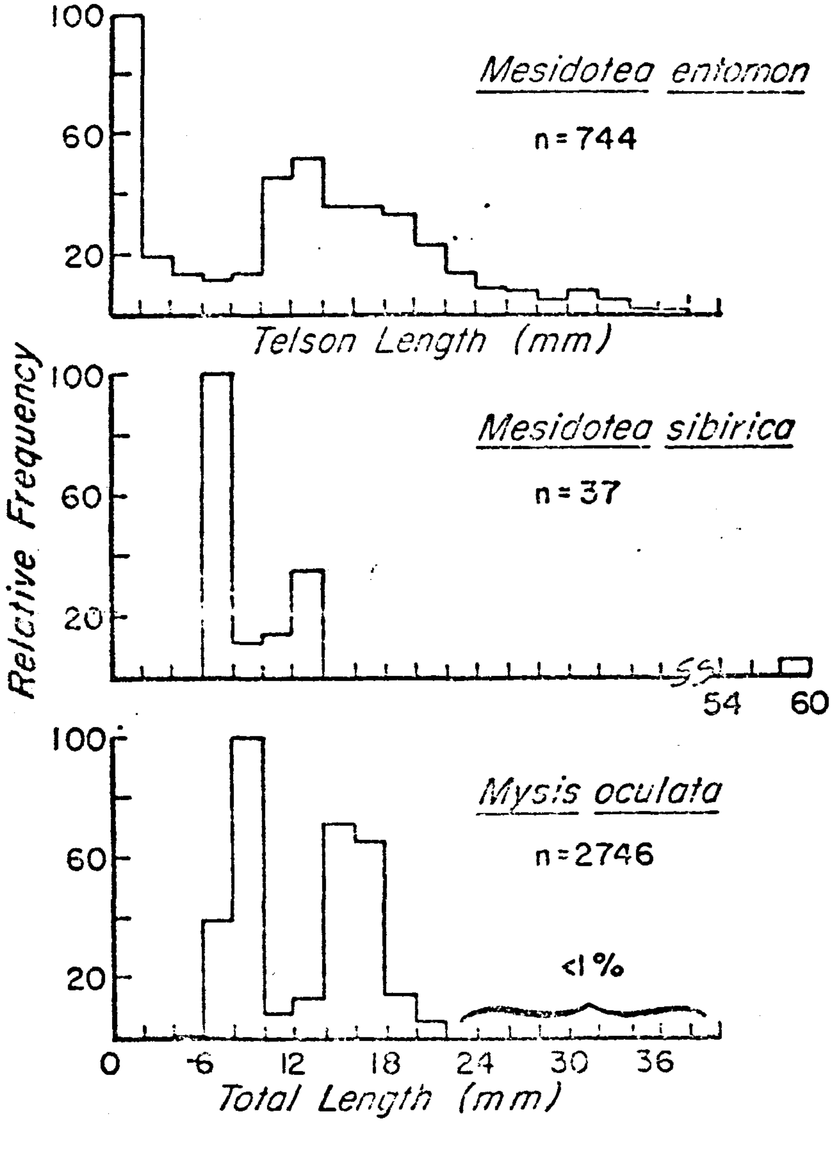
In M. entomon and M. sibirica the very large "two-year" olds often had brood pouches with eggs, no eggs, or small isopods which form the first size class when released.

Telson length was measured for all M. entomon and plotted against the total length of selected specimens. The equation for the regression of total length on telson length is:

$$Y = 2.602 + 2.532X$$

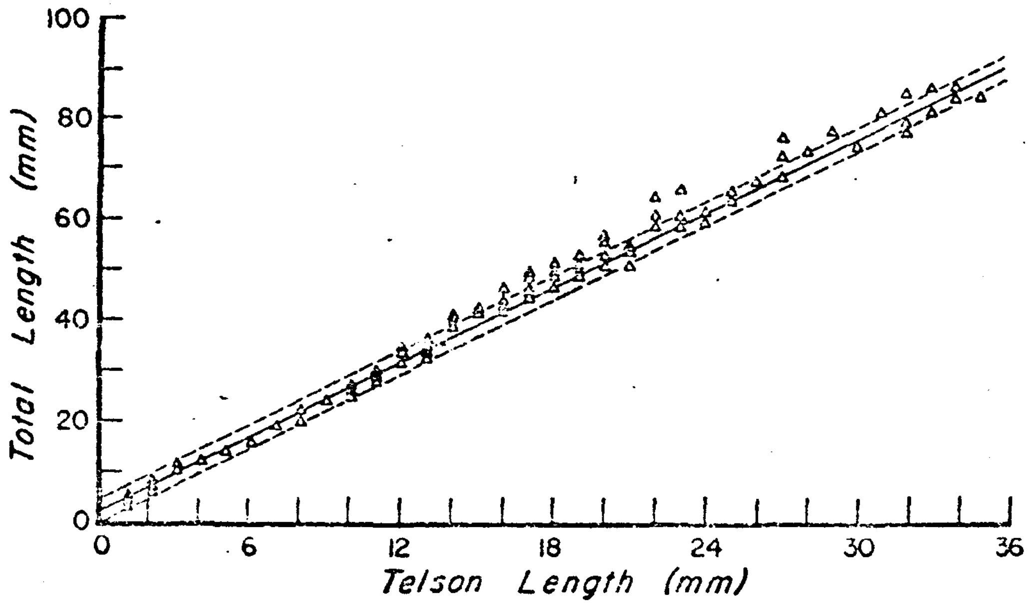
where Y is total length in millimeters and X is the telson length also in millimeters (Fig. 14, Appendix VII). Using this relationship, the total lengths of individuals whose telsons have been measured can be determined. Telson length was considered the most representative measure because the telson apparently does not change its length with preservation. Of the three species of Mesidotea found, two are similar

Fig. 13. Combined distribution of *Mesidotea entomon*, *Mesidotea sibirica*, and *Mysis oculata* size classes in the Colville study area.



100
60
20
Mesidotea entomon
n=744
Telson Length (mm)
Relative Frequency
100
60
20
Mesidotea sibirica
n=37
54
60
100
60
20
Mysis oculata
n=2746
<1%
0
6
12
18
24
30
36
Total Length (mm)

Fig. 14. Relationship between total length and telson length for *Mesidotea entomon*. Regression line and one standard deviation about the line for juveniles, sub-adults, females and males.



Total Length (mm)
0
20
40
60
80
100
Telson Length (mm)
0
6
12
18
24
30
36

as adults, but easily distinguished when very young. The paper by Menzies and Mohr (1963) describes the differences between the juveniles of all three species, but does not separate the adults adequately. Gurjanova (1933) has written a key to arctic isopod adults but this work is in German and the use of terms is confusing. To identify these isopods, I propose a key based on Gurjanova (1933) and my own observations (Table 6). The ratio, telson length to total length, is used as an identifying characteristic in this key.

4.4 Biomass

Formalin dry weights were measured for Mesidotea entomon juveniles, males, females (Appendix VIII), and for an aggregate of Mysis oculata (Appendix IX). These weights were then regressed on measures of length for purposes of converting size-class information to estimates of dry weight:

$$\text{Log } Y_J = (-1.9867 + 0.3372\ X) - 2;\ \text{Juveniles} \quad \ldots\ldots\ldots \quad (E)$$

$$\text{Log } Y_F = (0.1132 + 0.0697\ X) - 2;\ \text{Females} \quad \ldots\ldots\ldots\ldots \quad (F)$$

$$\text{Log } Y_M = (0.339 + 0.055\ X) - 2;\ \text{Males} \quad \ldots\ldots\ldots\ldots\ldots \quad (G)$$

Where Y is the predicted formalin dry weight in milligrams Mesidotea entomon in size class X (telson length; APPENDIX VIII); the integer two corrects for coding. Using Lark's test (Lark, 1965), the regressions were found to differ significantly by category (Fig. 15).

Two equations are necessary to describe the relationship between formalin dry weight and length for Mysis oculata:

Table 6. Key to the isopod genus _Mesidotea_ in the near-shore Colville region, Beaufort Sea

1(2) Eyes lacking . . . . _Mesidotea sabini sabini_

2(1) Eyes present 3

3(6) Telson short and broad, flagellum has less than 12 segments 4

4(5) Epimere 1 or 2 has hairs on margin, telson: total length = approx. (.27) . . . _M. sibirica_ adult

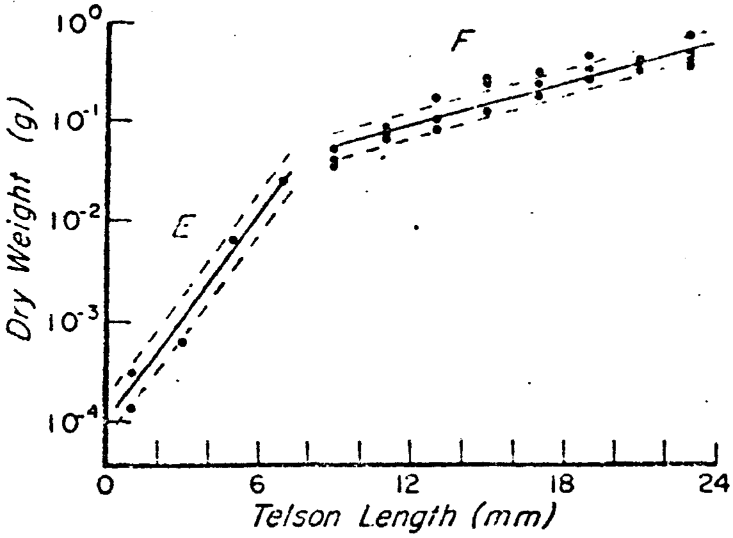
5(4) Epimeres bare and smooth, telson: total length = approx. (.30+) . . _M. sibirica_ juvenile

6(3) Telson long and th-n, flagellum has 12 or more segments 7

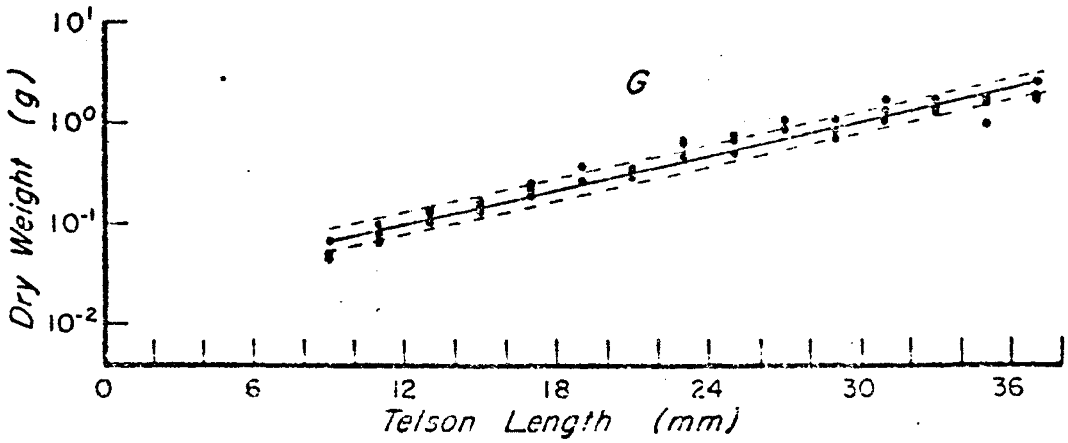
7(8) Telson: total length = approx. (.35 to .40) . . . . _M. entomon entomon_ adult

8(7) Telson: total length = approx. (.25 to .32) . . . . _M. entomon entomon_ juvenile

Fig. 15. Relationship between dry weight and telson length for *Mesidotea entomon* males (G), females (F) and juveniles (E). Regression line and one standard deviation about the line depicted.



Dry Weight (g)
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
E
F
0
6
12
18
24
Telson Length (mm)



Dry Weight (g)
10¹
10⁰
10⁻¹
10⁻²
G
0
6
12
18
24
30
36
Telson Length (mm)

$$\text{Log } Y_I = (-2.3310 + 0.2012X)-3 \quad \text{(H)}$$

$$\text{Log } Y_{II} = (0.1946 + 0.0371X)-3 \quad \text{(I)}$$

again where Y is the predicted weight for a mysid in size class X (total length; APPENDIX IX); the integer three corrects for coding. Equation H is for mysids of total length from 7 to 15 mm; equation I is for total lengths of 15 to 39 mm (Fig. 16, APPENDIX IX).

Mesidotea entomon and *Mysis oculata* were further analyzed for carbon content and equations calculated relating the organisms size and carbon content (Fig. 17):

$$Y_{mo} = 50.92 - 0.039\ X; \textit{ Mysis oculata} \quad \text{(J)}$$

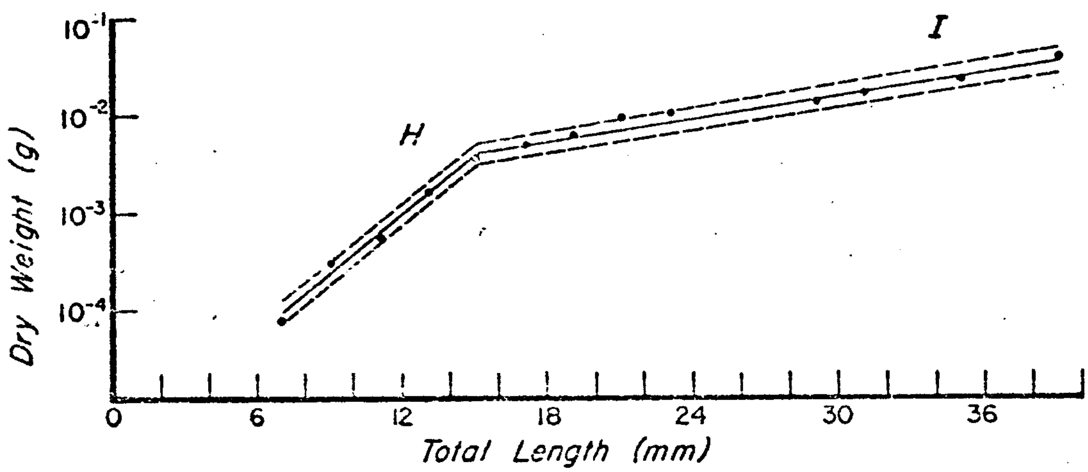
$$Y_{me} = 31.34 + 0.0295\ X; \textit{ Mesidotea entomon} \quad \text{(K)}$$

Y is the percentage carbon per unit of dry weight, and X is the telson length (isopod) or total length (mysid) in mm. This data was also used to convert dry weight to carbon for standing stock estimates.

Selected other common species were analyzed for carbon (Table 7). Carbon content of these organisms ranged from a low of about 16 percent for juvenile *M. sibirica* and *Acanthostepheia* sp. (amphipod) to about 51 percent for *Mysis oculata* and 31 percent for *M. entomon*; the content for other species fell within this range (Table 7).

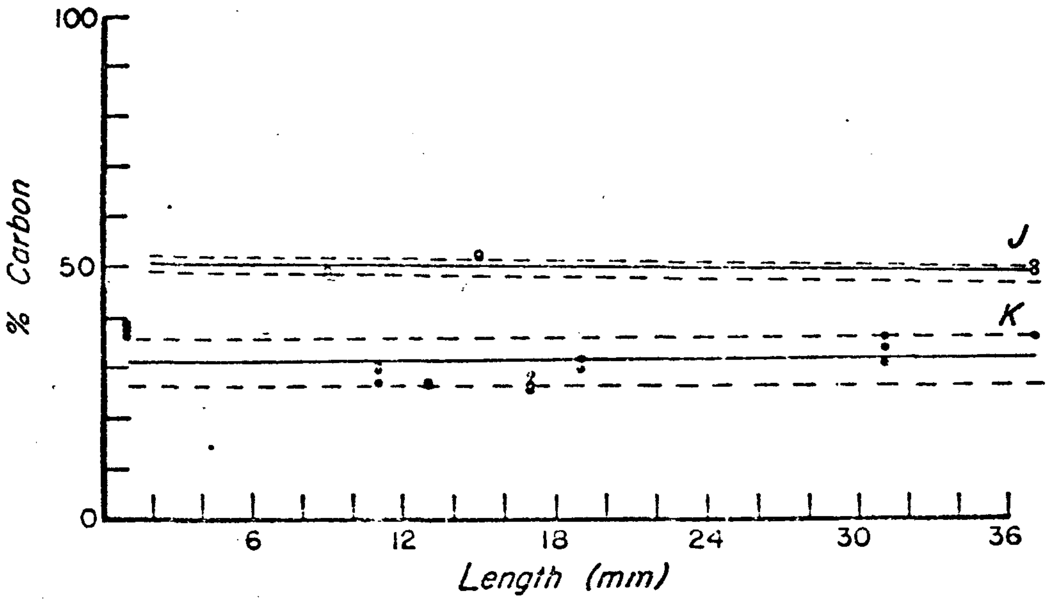
Estimates of standing stock carbon were made for male, female and juvenile *Mesidotea entomon*, and *Mysis oculata* using data from trawl samples (Table 8). The highest mysid standing stock, 28.26 mgC/m^2, occurred in the nearshore Beaufort Sea while the stock

Fig. 16. Relationship between dry weight and total length for *Mysis oculata*. Regression line and one standard deviation about the line depicted.



Dry Weight (g)
10⁻¹
10⁻²
10⁻³
10⁻⁴
Total Length (mm)
0
6
12
18
24
30
36
H
I

Fig. 17. Carbon content as a percentage of dry weight in relation to total length for Mysis oculata (J) and to telson length for Mesidotea entomon (K).



100
50
0
% Carbon
J
K
6
12
18
24
30
36
Length (mm)

Table 7. Average per cent carbon content of some common species collected in the Colville region.

	Per Cent
Mysis oculata	50.12
Ampharete vega	46.54
Gammarus locustus	46.05
Gammaracanthus loricatus	46.05
Cyrtodaria kurriana	43.98
Yoldia arctica	37.52
Pseudalibrotus litoralis	37.39
Mesidotea entomon	31.85
Mesidotea sibirica (juveniles)	17.89
Acanthostepheia behringiensis	16.46

Table 8. Estimated standing stocks (mg C/m^2) of *M. entomon* and *Mysis oculata*

	Harrison Bay	Beaufort Sea	Simpson Lagoon	Deep Simpson Lagoon	Shallow Simpson Lagoon
Mysis oculata	3.36	28.26	1.99	--	--
M. entomon					
Juveniles	.01	.01	.02	.001	.07
Males	.52	6.61	.07	.04	.20
Females	.02	2.60	.02	0	.05
Total	.58	9.24	.18	.04	.31

in Harrison Bay and Simpson Lagoon was much lower. For most *Mesidotea entomon*, the nearshore Beaufort Sea also exhibited the highest stock; juveniles were the sole exception. The biomass of all *M. entomon* outside the barrier islands averaged 9.24 mgC/m^2. The standing stock of *Mysis oculata* was consistently higher than that of *M. entomon* in all areas. In Harrison Bay, the total mysid stock was approximately six times greater than that of isopods, while in the nearshore Beaufort Sea the mysids were three times greater. In Simpson Lagoon the mysid stock exceeded the isopods by an order of magnitude.

Dry weights were also determined for all organisms collected in the grab samples (Table 4). For deep Simpson Lagoon the average biomass was 11.74 $\pm$ 13.58 g/m^2 (dry weight); for shallow Simpson Lagoon 0.46 $\pm$ 0.44 g/m^2; and for Harrison Bay 0.48 $\pm$ 0.94 g/m^2. The total organism biomass in deep Simpson Lagoon differed significantly ($P<0.05$) from that in the other two areas; shallow Simpson Lagoon and Harrison Bay were similar in biomass. The pelecypod *Cyrtodaria Kurriana* with its shell accounted for the largest average biomass (9.61 $\pm$ 13.69 g/m^2) in deep Simpson Lagoon. This organism was not collected in either of the other areas. Another pelecypod, *Yoldia arctica* and a tunicate, *Mogula oregonia* account for a large portion of the weight of the infauna of deep Simpson Lagoon at 0.66 $\pm$ 2.04 g/m^2 and 0.29 $\pm$ 0.85 g/m^2 respectively. No infaunal animals occurred in shallow Simpson Lagoon and only one infaunal species, a polychaete Spio filicornia, was found in samples from Harrison Bay. In both of these areas, the epifaunal amphipods and isopods made up the bulk of the meager biomass.

Chapter 5

DISCUSSION

5.1 General Physical Characteristics

The northernmost arctic coast of the United States is characterized by numerous shallow lagoons and bays where ice is present at least 11 months of the year, sometimes all year round (McRoy *et al.*, 1969). Due to the shallow nature of these estuaries, the shorefast ice in many areas is frozen into the sediments for much of the year. The bottom water remaining in isolated deeper areas is high in salinity, sometimes "ultrasaline," is generally below 0°C., and may be deficient in oxygen (Faas, 1969). As the ice breaks up, the bottoms of the estuaries near shore are ground and scoured by the moving flows.

In the months of open water, melting sea ice and runoff from adjacent streams and rivers produces turbid, low salinity water near the coast subject to occasional drastic wind influenced changes in sea level (Kinney *et al.*, 1972).

5.2 The Nearshore Benthos

The shallow nearshore environment would seem to be unfit for any kind of biota; indeed, the beaches surrounding the Colville estuarine complex bear out this contention as they are seemingly barren of macroscopic life. On the other hand, the deeper waters (> 2m) of Simpson Lagoon, Harrison Bay, and especially the nearshore Beaufort Sea support a biota in which a number of species are present in some abundance. Organisms living in the region must be able to cope with low temperatures, salinities varying over a wide range, being frozen in and scoured by ice, and perhaps subjected to conditions of low oxygen.

Crustaceans, molluscs, and polychaetes characterize the fauna of the area with a few species responsible for most of the abundance and biomass. This is to be expected since the population encountered is representative of the biota of most arctic environments (Dunbar, 1968; Thorson, 1936 and 1957). Physical factors here are probably more important in determining the composition of the biota than biological interactions such as competition and predation (Fischer, 1960; Pianka, 1966). In nearshore Antarctic studies Dayton et al. (1970) demonstrated that biological competition and predation is almost non-existent in the ice scour zone. Similarly, in arctic environments the number of predators is few, biological competition is at a minimum (Dunbar, 1968) and species diversity in terms of an absolute number of species is low (Thorson, 1959).

In this general context, pressures from the physical environment appear to mediate the species composition, abundance, and biomass of the nearshore community of the Colville River estuary. The physical harshness of this nearshore region is evidently responsible for a low number of predator-prey relationships. Only two epifaunal predators occurred in samples, the sea spider *Nymphon grossipes* and *Mesidotea entomon*, and only one of them, the former, is exclusively carnivorous (Barnes, 1966). However, *Nymphon grossipes* is rare in the region and *M. entomon* is usually classified as a scavenger (Green, 1959). Two infaunal predators were present, the priapulid *Priapulus caudatus* and one specimen of a nemertean, *Cerebratulus marginatus* (Barnes, 1966).

Harsh physical conditions may also be responsible for the low species diversity observed in samples; only 47 species were collected using a trawl and grab. In order to compare the number of species observed in the Simpson Lagoon-Harrison Bay area with Sanders (1968), I chose data from 6 randomly selected grab samples (each 0.05 m^2). A total of 17 species occurred in my combined sample, while a second composite of six additional grabs contained no organisms. In comparison with values published by Sanders for other marine and estuarine environments where between 0.3 and 0.8 m^2 of sea bed were examined, this arctic estuary exhibits very few species (Table 9).

Table 9. A comparison of the number of species occurring for various marine and estuarine environments.

Type	No. species/station	Author
Arctic estuary	0-17	This Study
Boreal estuary	10-30	Sanders, 1968
Tropical estuary	21-26	Sanders, 1968
Stress shallow tropical marine	30-33	"
Boreal shallow water	16-21	"
Tropical shallow marine	39-11	"
Outer continental shelf	51-75	"
Deep sea (slope)	47-96	"

5.2.1 Environmental Interactions

Three factors--ice, salinity variations, and perhaps concentrations of dissolved oxygen--affect the organisms in the region. Simpson Lagoon would appear to be the most physically stressed area because its shallow depths are subject to severe current fluctuations in the ice-free season. In the winter when the water in Simpson Lagoon is isolated from both Harrison Bay and the Beaufort Sea by bottom fast ice, the pools of high salinity water (up to 68 °/₀₀) that form beneath the ice undoubtedly have a detrimental effect on the fauna. Since the average depth of this lagoon is but two meters, only a small portion, a narrow trough running the length of the lagoon, would not be frozen to the bottom. It is also quite probable that dissolved oxygen values drop to very low levels in these isolated pockets; areas of this type (very low dissolved O_2 values) have been found in the nearby Colville Delta (Kinney *et al.*, 1971).

Since *Mesidotea entomon* is known to be tolerant of salinities ranging from very dilute (even freshwater) to normal salinity (Lockwood and Croghan, 1957), it is easy to understand why this species occurs in Simpson Lagoon during the ice-free season. However, since the literature on *M. entomon* places its upper range of salinity tolerance at "normal" oceanic seawater (Green, 1968), I would not expect the organism to survive in ultra-saline pockets of water under the ice. I suspect that the *Mesidotea entomon* migrates outside the barrier islands or into deeper Harrison Bay where "more" oceanic salinities are found during the period of ice cover. *Mysis oculata* also exhibits a salinity tolerance range from very dilute water to oceanic salinities, and so this species probably migrates offshore as the ice forms. Thus, in areas where ice extends into the bottom, the mobile organisms either migrate to deeper oceanic water or perish. Holmquist (1963) has noted that individuals of the genus *Mysis* can not survive freezing. I believe it is unlikely that *Mesidotea* could survive for extended periods in the ice. In the Antarctic, epifaunal species were found to migrate from the zone of ice scour until open water occurred (Dayton *et al.*, 1970). A third stress, that of low oxygen values, perhaps even anoxic conditions in the isolated deeper pockets in Simpson Lagoon, would also be an incentive promoting seasonal migration.

The infauna constitute another situation since they are not highly mobile. These organisms either survive high salinity, possibly near anoxic conditions, and being frozen into the ice, or die and are replaced by recruitment from deeper water. Certain molluscs are known to survive in ice without ill effects (Holmquist, 1963). In addition living *Cyrtodaria kurriana*, *Yoldia arctica*, and tube polychaetes were found living in the shallow water just under the ice. Similar fauna were found existing in anoxic conditions under one meter of ice in Safety Lagoon near Nome, Alaska (McRoy, 1969). It may be reasonable to suppose then that at least some molluscs and tube dwelling polychaetes can survive the stressed environment under and in the ice.

It is apparent that in the very shallow parts of the lagoon ice scouring prevents organisms from establishing populations. No infaunal species were found in either Simpson Lagoon or Harrison Bay in the grab samples taken at depths of less than two meters. Only mobile epifaunal species occurred in these shallow depths. This pattern may also be influenced by the quality of the substrate since sand and gravel predominated in the shallower depths while sandy mud (more suitable for burrowing) was found in the deeper zones. However, it is most probable that the shallows are rarely populated by infauna or non-motile epifauna because of the effects of bottom-fast ice over most of the year and scouring during breakup. Even hydroids which attach to gravel were absent.

5.2.2 Distribution Patterns

Three species of *Mesidotea*, *M. entomon*, *M. sibinca*, and *M. sabini* were found together at at least two stations, and *M. entomon* and

M. sibirica occurred in common at twelve stations. According to Dunbar (1968), arctic areas have a small number of niches, so it seems curious that three species of the genus Mesidotea, all thought to be scavengers or detritus feeders, would be found in the same environment. Gurjanova (1946 and 1970), reports that M. sabini is a deep water form. However, this species was found in Harrison Bay and Simpson Lagoon in less than three meters of water. The LCM Red expedition (Sparks and Pereyra, 1966) also found M. sabini in Harrison Bay. M. sibirica, considered a more oceanic form (Ekman, 1967), was not very abundant although they were more numerous than M. sabini and because of their low numbers, they probably do not enter into direct competition with the M. entomon. Simpson Lagoon and the river delta area also have a great deal of peat and organic detritus deposited in them. Such high concentrations of detritus could support a large variety of omnivorous scavengers (Green, 1957).

The distribution of organisms within the areas examined was very patchy. Trawl catch values ranged from 0 at one station to hundreds at another for isopods, and from approximately 1,600 to 120,000 for the mysids. Grab catches were variable from station to station indicating the patchy nature of the benthos. An index of dispersion has shown the infauna to be more patchy than the epifauna.

Abundance and biomass data determined from trawling for Mysis oculata, M. entomon (males, females, total excluding juveniles), and amphipods show that both are many times more numerous in the zone outside the barrier islands (>4.8 m) than in either Harrison Bay or Simpson Lagoon. Catch records from the Colville region for the summer of 1970, although not quantitative due to varying times of tows and the use of a wide-mesh otter trawl indicate that only a few _M. entomon_ were collected within Simpson Lagoon while hundreds were found just outside of the barrier islands (Kinney _et al._, 1971). This information indicates that at least for adult _M. entomon_, my results are supported by the data from the previous summer. Due to their smaller size, _Mysis oculata_ were not compared since the 1970 trawl mesh was too large.

Although MacGinitie (1955) suggested that _M. entomon_ preferred very dilute salinity water, I found the greatest numbers of this species in the higher salinity waters outside of the barrier islands. The only _M. entomon_ found in the lagoon in any abundance were the recently released juveniles which occurred in the same number as juveniles found in the off-island areas. _M. entomon_ generally were more abundant in the shallower parts of the lagoon than in the deeper areas. This distribution may be related to substrate preference, or to reproductive or developmental processes.

The grab survey revealed that the biomass and abundance of infauna in Simpson Lagoon and Harrison Bay were very low. These values correspond closely to the barren zone of 0-5 meters found in other arctic areas of Eastern Canada and Scandinavia (Ellis, 1960). The next deeper zone starting at about five meters, has much higher biomass and abundance values. The Soviets also consider five meters to be the depth at which the littoral zone of the Chukotsk Sea begins to be populated by benthic organisms (Zenkevitch, 1963).

The survey of the western Alaskan arctic coast above the Bering Strait (Sparks and Pereyra, 1966) concluded that benthic invertebrate populations are probably not established in water less than 20 feet deep due to the effects of ice scour, and that only highly motile forms that move in and out with the seasons occur there. The low salinity lagoons behind the barrier beaches did not contain large populations of invertebrates. The animals present in these lagoons were either euryhaline forms or those washed in from the sea. In general, these distribution patterns were also observed in the Colville area. My results of much greater abundance of benthos beyond the 5-m depth come from trawl data only, but it is likely that a grab survey outside the barrier islands would demonstrate larger populations of infauna than were found in either Harrison Bay or Simpson Lagoon. Estimates of standing stock from this arctic estuary are probably comparable only to other high latitude estuaries, some areas of the deep sea, and some polluted areas (Table 10).

The molluscs Hiatella arctica and Nucula tenuis were the most common nearshore pelecypods found by MacGinitie (1955), in the Barrow

Table 10. Abundance and biomass of benthic organisms selected from some specific regimes of the world oceans.

Area	Abundance No/m^2	Author
Simpson Lagoon-Harrison Bay	22±33-313±230	This Study
Elbe Estuary	7,025-20,100	Hedgpeth, 1957
North Baffin Island (0-3m)	381	Ellis, 1960
Frustration Bay (5m)	282	Ellis, 1960
Buzzards Bay	39,628	Sanders, 1958
Sargasso Sea abyss	30-130	Sanders *et al.*, 1965
Gulf Stream abyss	150-270	Sanders *et al.*, 1965
Continental slope	120-750	Sanders *et al.*, 1965

Area	Biomass g/m^2	Author
Simpson Lagoon-Harrison Bay	.46±.44-11.74±13.58 (dry wt.)*	This Study
North European estuary	16 (rough weight)	Hedgpeth, 1957
Puget Sound	8-19 (dry wt.)*	Lie, 1968
Chukchi Sea sublittoral	200 (wet wt.)	Zenkevitch, 1963
Chukchi Sea littoral	24 (wet wt.)	Zenkevitch, 1963
Pacific deep sea (950-6000 m)	0.01-6.94 (wet wt.)	Zenkevitch, 1963
Antarctic benthos	400-500 (wet. wt.?)	Knox, 1970
Bering Sea Strait	500+ (wet. wt.)	Zenkevitch, 1963
North Baffin Island (0-3m)	31 (wet wt.)	Ellis, 1960
North Baffin Island (5-14m)	201 (wet wt.)	Ellis, 1960
Frustration Bay (5m)	35 (wet wt.)	Ellis, 1960
Frustration Bay (15m)	210 (wet wt.)	Ellis, 1960

*Wet wt. = 2 to 3 X dry wt.

region. These species were not found in either this investigator's samples or in those of LCM Red. On the other hand, Cyrtodaria kurriana and Yoldia arctica, the most abundant species found in this investigation and that of the LCM Red (Hulsemann, 1962) were not reported by MacGinitie (1955) at all.

Comparing size-frequency histograms for M. entomon sampled in 1970 and 1971 (Figs. 9 and 10), it appears that the size distributions are not significantly different except that some smaller isopods are missing from the 1970 data presumably because of the otter trawl mesh size. Since both sets of data were taken in August and the results are seemingly similar, and a 2+ year life span is indicated, it is possible to estimate the productivity of the M. entomon as biomass at the time of collection divided by the turnover time of the population assuming steady state conditions. Since arctic species generally reproduce non-pelagically and recruitment is at a low uniform rate, and the annual turnover appears to be small, the annual production will probably be less than the standing stock at any one time (Thorson, 1957; Ellis, 1960). This is in contrast to more temperate regions where the productivity may be 2-5 times greater than the standing crop at any one time (Sanders, 1968). Therefore the standing crop figures found in Table 8 must be considered maximum values for productivity in g $C/m^2/yr$ since the population turnover probably exceeds one year;

reducing these values by a factor of 2.0 would perhaps provide more realistic estimates of isopod annual productivity. Similar reasoning can also be applied to the population of *Mysis oculata*.

5.2.3 Life History and Production

Mesidotea entomon, *Mesidotea sibirica*, *Mesidotea sabini* and *Mysis oculata* all brood their young (Barnes, 1966). The eggs are spawned in a pouch where they develop to juveniles. These organisms, as is characteristic for most arctic species, do not have pelagic larval stages (Thorson, 1936).

M. entomon appears to have continuous egg laying and development throughout the year according to MacGinitie (1955). This statement is based on the fact that he found young isopods in the brood pouches in mid-July and newly spawned eggs in late October. Generally the eggs are spawned from late August to at least late October and the young develop in the brood pouches until they are released the following summer. Other species of isopods have been found to hold their eggs for as long as 102 days depending on the temperature. The arctic species probably have slower development (Thorson, 1936; Dunbar, 1968). Dunbar (1968) states that many arctic species spawn in late fall or early winter when the food supply is supposed to be at a minimum. In August 1971, young *Mysis oculata* were collected as well as adult females with empty brood pouches. The young appear to be released in summer as with the isopods.

Three size classes are noted on the length frequency diagrams for *M. entomon* and *Mysis oculata*. This indicates that the organisms probably live fewer than three years. The smallest group is the recently hatched juveniles, the second size class corresponds to the one-year olds, and the third group is comprized of two-year old individuals. Only two size classes are found for *M. sibirica*, but a large gap occurs in the frequency distribution suggesting that an intermediate mode exists somewhere, perhaps outside of the sampling area. Dunbar (1968) suggests that the two year life span is actually quite common in the arctic. Growth and development are retarded such that a species that has a one year life span and spawns more than once a year in temperate zones may have a two year or prolonged life span and spawn only once a year in the arctic (Dunbar, 1968; Geiger, 1969).

5.2.4 Trophic Relations

Standing stock as gC/m^2 has been calculated for *Mesidotea entomon* and *Mysis oculata* (Table 10), and the carbon content of other common species measured (Table 7). Curl (1962) discussed the analysis of carbon and its significance. Unfortunately carbon values give only a rough indication of how much value a species may be to predators since it is not known how much of the carbon can be utilized. However, it is known though that mysids, isopods, and amphipods are a part of the diet of various arctic fish such as Arctic char (Salvelinus malma), the sculpin (Myoxocephalus quadricornis), and the "white fish" (Coregonus spp.) (Schmitt, 1919). Since most of the benthic organisms in the region are scavengers, and deposit or suspension feeders, they probably have an adequate supply of food. Suspended organics are supplied in great quantity by the river; large lumps of peat occurred in trawl samples taken inside the barrier islands.

5.2.5 Sources of Error

Experimental error in sampling procedure, measurements, and computation of standing stock estimates could account for some of the variability in the abundance and biomass values, but care was taken to minimize those sources that could be practically lessened. Other sources of variability are inherent in the methods used and are difficult if not impossible to overcome.

The use of a .05 m^2 grab rather than a .1 or .2 m^2 sampler introduces sampling error (Holme and MacIntyre, 1971), but the size and weight of the gear was governed by the type of vessel which was available to work the very shallow lagoons. Attempts were made to keep only samples that collected three or more liters of sediment. With the smaller sampler, certain deep burrowing organisms may be missed such as Mya spp. or Echuirus spp. However, since over 90% of the organisms occur in the upper 15 cm or so, most of the organisms present were probably sampled.

To reduce a source of error that could affect the comparison of mysid and isopod abundance differences between areas, geometric rather than arithmetic means were examined. Arithmetic means of data sets are in most instances much higher than geometric means, an effect observed when extremely wide ranges of values are encountered. The geometric mean, already slightly negatively biased, lessens the effect of the very divergent values.

The estimates of isopod and mysid standing stock are variable depending on the deviations of dry weight values from the mean that was used for the calculation, the loss of weight reflected in the dry weight values caused by preservation in formalin, the effect of formalin preservation on average carbon contents of the organisms, and for the mysids the variability inherent in the splitting of samples into subsamples. The effect of formalin preservation on the carbon content is not known; formalin leaching reduces dry weights by 10 percent or more. The variability caused by subsampling is relatively minimal (Cooney, 1971).

5.7 Future Studies

Few or no seasonal biological studies have been conducted in the Colville delta area. The problem of examining physiological adaptations by organisms to the multiple stresses present: freezing temperatures; varying salinities; and anoxic conditions under the ice, should be considered. An investigation of the "ultrasaline," possibly anoxic, isolated pockets under the Simpson Lagoon ice would be most useful to complete the seasonal picture of arctic nearshore benthos. However, a routine methodology must be perfected to provide adequate samples through almost two meters of ice. Small baited traps could be employed without much difficulty.

A number of factors must be taken into account in any future investigation. The weather is extremely severe with high winds, pack ice, fog and rough water the norm in the summer season, and extreme cold, high winds, and ice and snow prevalent in the winter. I found that it was not unusual to have six unworkable days to every one workable day. The lagoonal areas are accessible only to small craft in the summer and snowmobile or cat-trains in the winter. Since the lagoon bottoms are covered with mounds of peat washed in from the tundra, trawl samples usually are filled with this material. Much time is required to unravel the organisms from it. An investigator should be aware of the time required for this operation.

REFERENCES

Alexander, V. and M. Billington. 1972. Primary productivity studies in the nearshore Colville River estuarine region, p. 208-216. In P. Kinney, D. Schell, V. Alexander, D. Burrell, R. Cooney, and A. Naidu. Baseline data study of the Alaskan arctic aquatic environment, 1971. Univ. Alaska, Inst. Mar. Sci. Rept. R72-3.

Barnes, R. 1966. Invertebrate Zoology. W. B. Saunders Co., Philadelphia. 632 p.

Cooney, R. T. 1971. Zooplankton and micronekton associated with a diffuse sound-scattering layer in Puget Sound, Washington. Ph.D. Dissert., Univ. Washington.

Curl, H. 1962. Analysis of carbon in marine plankton organisms. J. Mar. Res. 20(3): 181-188.

Dayton, P., G. Robilliard, and R. Paine. 1970. Benthic faunal zonation as a result of anchor ice at McMurdo Sound, Antarctica, p. 244-258. In M. Holdgate, ed., Antarctic ecology I. Academic Press, New York.

Dixon, W. J. 1965. BMD biomedical computer programs. Health Sciences Computing Facility, Dept. Preventive Medicine and Public Health, School of Medicine, Univ. Calif., Los Angeles. 620 p.

Dunbar, M. 1968. Ecological development in polar regions. Prentice-Hall, New Jersey. 119 p.

Dygas, J., R. Tucker, and D. Burrell. 1972. Geological report of the heavy minerals, sediment transport and shoreline changes of the barrier islands and coast between Oliktok Point and Beechey Point, p. 61-121. In P. Kinney, D. Schell, V. Alexander, D. Burrell, R. Cooney, and A. Naidu. Baseline data study of the Alaskan arctic aquatic environment, 1971. Univ. Alaska, Inst. Mar. Sci. Rept. R72-3.

Ellis, D. 1960. Marine infaunal benthos in Arctic North America. Arctic Inst. N. Amer., Tech. Paper No. 5,53 p.

Ekman, S. 1967. Zoogeography of the sea. Sidgwick & Jackson, London. 417 p.

Faas, R. 1969. Inshore arctic ecosystems with ice stress, pp. 987-1003. In H. Odum, J. Copeland, and E. McMahan (eds.) Coastal ecological systems of the United States: A source book for estuarine planning. Univ. of North Carolina, Institute of Marine Science Report 68-128.

Fischer, A. 1960. Latitudinal variations in organic diversity. Evolution 14: 64-81

Geiger, S. 1969. Distribution and development of mysids (Crustacea, Mysidacea) from the Arctic Ocean and confluent seas. Bull So. Calif. Acad. Sci. 38(2): 103-111.

Given, R. 1965. Five collections of Cumacea from the Alaskan Arctic. Arctic 18(4): 213-229

Green, J. 1957. The feeding mechanism of *Mesidotes entomon* (Limn.) Proc. Zool. Soc. Lond. 129: 245-254.

_______. 1968. The biology of estuarine animals. Univ. Wash. Press, Seattle. 401 p.

Gurjanova, E. 1933. Die marinen Isopoden der Arktis. In F. Romer and F. Schaudinn, Fauna Arctica 6(5): 392-488.

__________________. 1946. Individual and age variability of the marine assel and its importance in evolution of the genus Mesidotea Rich. TRUDY, OF THE ZIN AS USSR 8(1); 105-144. (English summary)

__________________. 1970. Special features in the fauna of the Arctic Ocean and their value in understanding the history of the formation of the fauna. p. 126-161. In The Order of Lenin Arctic and Antarctic Institute of Scientific Research. The Arctic Ocean and its shores during the Cenozoic. Hydrometeorological Publ., Leningrad.

Hedgpeth, J. 1957. Estuaries and lagoons: II-Biological aspects, p. 693-729. In J. W. Hedgpeth (ed.) Treatise on Marine ecology and paleoecology, Vol. I. Ecology. Geol. Soc. Amer. Mem. 67.

Holme, N. and A. McIntyre. 1971. Methods for the study of marine benthos. IBP Handbook no. 16. Blackwell Scientific Publications, Oxford. 334 p.

Holmquist, C. 1963. Some notes on Mysis relicta and its relatives in northern Alaska. Arctic 16(2): 109-128.

Hulsemann, K. 1962. Marine Pelecypoda from the north Alaska coast, The Veliger 5(2): 67-73.

Hulsemann, K. and J. Soule. 1962. Bryozoa from the Arctic Alaska coast. Arctic 15:228-230.

Kaestner, A. 1970. Invertebrate Zoology III. Crustacea, Wiley Interscience Publ., New York. 523 p.

Kinney, P., D. Schell, V. Alexander, D. Burrell, R. Cooney, and A. Naidu. 1972. Baseline data study of the Alaskan arctic aquatic environment, 1971. Univ. Alaska, Inst. Mar. Sci. Rept. R-72-3.

Kinney, P., D. Schell, J. Dygas, R. Nenahlo, and G. Hall. 1972. Nearshore currents, p. 29-48. In P. Kinney, D. Schell, V. Alexander, D. Burrell, R. Cooney, and A. S. Naidu. 1972. Baseline data study of the Alaskan arctic aquatic environment, 1971. Univ. Alaska, Inst. Mar. Sci. Rept. R-72-3.

Kinney, P. D. Schell, V. Alexander, S. Naidu, C. P. McRoy, and D. Burrell. 1971. Baseline data study of the Alaskan arctic aquatic environments; eight month progress report, 1970. Univ. Alaska, Inst. Mar. Sci. Rept. R-71-4. 176 p.

Knox, G. 1970. Antarctic marine ecosystems, pp. 69-96. In M. Holdgate (ed) Antarctic ecology. Vol. 1. Academic Press, New York. 604 p.

Lark, P. 1965. Chemical calculations. New South Wales Univ. Press, Sydney. 101 p.

Lie, U. 1968. A quantitative study of benthic infauna in Puget Sound, Washington, U.S.A., in 1963-1964. FiskDir. Skr. Serv HavUnders., 14:229-556.

Lockwood, A. and P. Croghan. 1957. The chloride regulation of the brackish and fresh-water races of Mesidotea entomon (L.) J. exp. Biol. 34: 253-258.

Lovegrove, T. 1966. The determination of the dry weight of plankton and the effect of various factors on the values obtained, p. 429-467. In H. Barnes. 1966. Some contemporary studies in marine science. Allen and Unwin, London.

MacGinitie, G. 1955. Distribution and ecology of the marine invertebrates of Point Barrow, Alaska. Smithsonian Misc. Coll. 128 (9): 1-201.

MacGinitie, N. 1959. Marine Mollusca of Point Barrow, Alaska. Proc. U.S. Nat. Mus. 109(3412): 59-208.

McRoy, C. P. 1969. Eelgrass under arctic winter ice. Nature 224(5221), pp. 818-819.

McRoy, C. P. et al. Natural arctic ecosystems with ice stress. In H. Odum, J. Copeland and E. McMahan (eds.) Coastal ecological systems of the United States: A source book for estuarine planning (In press). Univ. of N. Carolina, Inst. Mar. Sci. Rept. 68-128.

Menzies, R. and J. Mohr. 1963. Benthic Ianaidacea and Isopoda from the Alaskan Arctic and the polar basin. Crustaceana 3(3): 192-212.

Pettibone, M. 1954. Marine Polychaete worms from Point Barrow, Alaska, with additional records from the North Atlantic and North Pacific. Proc. U. S. Nat. Mus. 103(3324): 203-355.

Pianka, E. 1966. Latitudinal gradients in species diversity: a review of concepts. Amer. Natur. 100(910): 33-46.

Sanders, H. 1958. Benthic studies in Buzzards Bay I. Animal-sediment relationships. Limnol. Oceanogr. 3(3): 245-258.

Sanders, H., R. Hessler, and G. Hampson. 1965. An introduction to the study of deep-sea benthic faunal assemblages along the Gay. Head-Bermuda transect. Deep-Sea Res., 12: 845-868.

______________. 1968. Marine benthic diversity: a comparative study. Amer. Natur. 102(925): 243-281.

Schell, D. and G. Hall. 1972. Water chemistry and nutrient regeneration process studies, p. 3-28. In P. Kinney, D. Scheel, V. Alexander,

D. Burrell, R. Cooney, and A. S. Naidu. 1972. Baseline data study of the Alaskan arctic aquatic environment, 1971. Univ. Alaska, Inst. Mar. Sci. Rept. R-72-3.

Schmitt, W. 1919. Schizopod Crustaceans. Rept. Canad. Arctic Exped. 1913-1918. 7(B).

Snedecor, G. 1962. Statistical methods. The Iowa State Univ. Press, Ames, Iowa. 534 p.

Sparks, A. and W. Pereyra. 1966. Benthic invertebrates of the southeastern Chukchi Sea, pp. 817-838. In N. Wilimovskey and I. Wolfe (eds) Environment of the Cape Thompson Region, Alaska.

Thorson, G. 1936. The larval development, growth, and metabolism of Arctic marine bottom invertebrates compared with those of other seas. Medd. on Grn. 100(6): 1-147.

Thorson, G. 1957. Bottom communities, pp. 461-534. In J. W. Hedgpeth (ed.) Treatise on marine ecology and paleolcology, Vol. 1, Geol. Soc. Amer. Mem., 67: 461-534.

Zenkevitch, L. 1963. The biology of the seas of the USSR. Allen and Unwin, London.

TAXONOMIC REFERENCES

Porifera

De Laubenfels, M. 1955. Sponges of the Alaskan Arctic. Smithsonian Misc. Coll. 121(6):1-22.

Hydroidea

Naumov, D. 1969. Hydroids and Hydromedusae of the U.S.S.R. Israel Program for Scientific Translations, Jerusalem. 660 p.

Nemertea

Coe, W. 1905. Nemerteans of the West and Northwest Coasts of America. Bull. Mus. Comp. Zool. at Harvard College 47:1-318.

Polychaeta

Berkeley, E. and C. Berkeley. 1948. Annelida, Polychaeta Errantia. In Canadian Pacific Fauna. Fish. Res. Bd. Canada, No. 96(1). 100 p.

___________________________. 1952. Annelida, Polychaeta Sedentaria. In Canadian Pacific Fauna. Fish. Res. Bd. Canada, No. 9b(2). 139 p.

Hartman, O. 1968. Atlas of the Errantiate Polychaetous Annelids from California. Allan Hancock Foundation, USC, Los Angeles. 828 p.

_________. 1969. Atlas of the Sedentariate Polychaetous Annelids from California. Allan Hancock Foundation, USC, Los Angeles. 812 p.

Pettibone, M. 1954. Marine Polychaete worms from Point Barrow, Alaska, with additional records from the North Atlantic and North Pacific. Proc. U. S. Nat. Mus. 103(3324):203-355.

Bryozoa

Hulsemann, K. and J. Soule. 1962. Bryozoa from the Arctic Alaska coast. Arctic 15: 228-230.

Priapulida

Barnes, R. 1966. Invertebrate Zoology. W. B. Saunders Co., Philadelphia. 632 pp.

Mollusca

Keen, A. M. 1963. Marine Molluscan Genera of Western North America. Stanford Univ. Press, Standford, Calif. 126 pp.

MacGinitie, N. 1959. Marine Mollusca of Point Barrow, Alaska. Proc. U. S. Nat. Mus. 109(3412): 59-208.

Mueller, G. 1971. Key to the Alaskan Mya. (In preparation.)

Oldroyd, I. 1924. The Marine Shells of the West Coast of North America. Vol. I. Stanford Univ. Publ., Calif. 297 p.

Pycnogonida

Hedgpeth, J. 1941. A key to the Pycnogonida of the Pacific coast of North America. Trans. San Diego Soc. Nat. Hist. 9(26):253-264.

Isopoda

Boone, P. 1920. Isopoda. Rept. Can. Arctic Exped. 1913-1918. 8(D):1-40.

Gurjanova, E. 1933. Die marinen Isopoden der Arctis. In J. Romer and F. Schaudinn, Fauna Arctica 6(5): 392-488.

Hatch, M. 1947. The Chelifera and Isopoda of Washington and adjacent regions. Univ. Wash. Publ. in Biol. 10(5): 155-274.

Menzies, R. and J. Mohr. 1963. Benthic Tanaidaces and Isopoda from the Alaskan Arctic and the polar basin. Crustaceans 3(3): 192-202.

Cumacea

Hart, J. 1969. Cumacea. In Marine Fauna of the San Juan Archipelago (Friday Harbor Keys). Univ. of Wash., Seattle.

Amphipoda

Barnard, J. 1969. The families and genera of marine Gammaridean Amphipoda. U. S. Nat. Mus. Bull. 271. 535 pp.

Tencati, J. 1970. Amphipods of the central Arctic. Univ. So. Calif. Dept. Biol. Sci. Tech. Rept. No. 2.

Mysidacea

Banner, A. 1948. A taxonomic study of the Mysidacea and Euphausiacea (Crustacea) of the Northeastern Pacific. Trans. Royal Canadian Inst. 27(57).

Banner, A. 1954. New records of Mysidacea and Euphansiacea from the Northeastern Pacific and adjacent areas. Pacific Science 8:125-139.

Holmquist, C. 1958. On a new species of the genus *Mysis*, with some notes on *Mysis oculata* (O. Fabricus). Medd. om Gron. 159 (4);1-17.

Chordata

Van Name, V. 1945. The North and South American Ascidians. Bull. Amer. Mus. Nat. Hist. 84: 1-476.

APPENDIX I

Station depth and sampling dates;
2-m trawl survey

Station[1]	Depth (m)	Date
Beaufort Sea		
3	7.5	8-1-71
4	6.6	8-1-71
5	4.9	8-1-71
6	6.2	8-2-71
7	6.6	8-2-71
8	6.6	8-2-71
9	6.6	8-2-71
10	6.6	8-2-71
11	6.6	8-2-71
12	6.6	8-2-71
13	6.6	8-2-71
14	6.6	8-2-71
15	6.8	8-9-71
16	6.2	8-9-71
17	6.6	8-9-71
18	5.9	8-9-71
19	5.9	8-9-71
20	5.9	8-9-71
Harrison Bay		
1	3.3	8-12-71
2	1.8	8-12-71
3	6.6	8-12-71
4	1.6	8-12-71
5	3.3	8-12-71
6	6.6	8-12-71
7	1.8	8-12-71
8	3.1	8-12-71
9	6.6	8-12-71
C1	1.8	8-13-71
C2	3.3	8-13-71

[1] See fig. 3.

APPENDIX I

Station[1]	Depth (m)	Date
Simpson Deep		
1	2.5	8-9-71
2	2.8	8-9-71
4	2.6	8-9-71
5	2.8	8-9-71
8	2.5	8-9-71
9	2.5	8-9-71
11	2.0	8-9-71
12	2.6	8-8-71
14	2.6	8-8-71
17	2.5	8-8-71
R3	2.8	8-9-71
R5	2.6	8-8-71
Simpson Shallow		
3	1.8	8-9-71
7	1.6	8-9-71
10	1.8	8-9-71
13	1.6	8-8-71
15	1.6	8-8-71
16	1.6	8-8-71
18	1.8	8-9-71
19	1.5	8-9-71
20	1.8	8-9-71
21	1.6	8-8-71
R2	1.5	8-9-71
R4	1.8	8-9-71

APPENDIX II

Station depths and sampling dates;
grab survey

Station[1]	Depth	Date
A	2.4	8-15-71
B	2.4	8-15-71
C	3.1	8-17-71
D	3.0	8-17-71
E	2.8	8-16-71
F	2.5	8-17-71
G	2.6	8-17-71
H	2.5	8-16-71
I	1.0	8-15-71
J	1.7	8-16-71
K	1.8	8-16-71
L	1.3	8-16-71
M	6.6	8-12-71
N	3.1	8-12-71
O	1.8	8-13-71

[1]See fig. 3.

APPENDIX III

Catch/station

Mysis oculata

Station[1]	Area: Harrison Bay	Simpson Shallow	Simpson Deep	Beaufort Sea
1	4640		496	
2	5868		288	
3	750	354		10464
4	93		528	77568
5	1832		1424	1616
6	668			1608
7	3320	518		1656
8	4416		212	4416
9	5056		828	13024
10		210		3984
11			162	4336
12			464	2640
13		2032		6240
14			3344	12416
15		2856		9216
16		1020	164	19328
17				40960
18		4192		119808
19		1552		30976
20		912		7744
21		2352		
C1	608			
C2	1584			
R2		312		
R3			66	
R4		2816		
R5			2832	

[1]See fig. 3.

APPENDIX IV Catch/station
Area

Station[1]	Harrison Bay				Simpson Shallow				
	J[2]	M	F	T	J	M	F	T	J
1	14	1	1	16					6
2	51	8	4	63					0
3	4	0	0	4	3	0	0	3	
4	0	0	0	0					0
5	0	0	0	0					2
6	0	2	2	4					
7	1	0	0	1	32	1	0	33	
8	2	0	0	2					0
9	0	3	0	3					9
10					2	0	0	2	
11									0
12									0
13					6	0	0	6	
14									0
15					3	1	0	4	
16					20	0	1	21	
17									0
18					339	0	0	339	
19					86	0	3	89	
20					36	1	0	37	
21					18	13	4	35	
C1	21	0	0	21					
C2	9	0	0	9					
R2					60	0	1	61	
R3									1
R4					23	0	0	23	
R5									0

[1] See fig. 3.

[2] J=Juvenile; M=Male; F=Female; T=Total

Mesidotea entomon

Simpson Deep			Beaufort Sea			
M	F	T	J	M	F	T
0	0	6				
0	0	0				
			0	108	61	169
0	0	0	7	181	154	342
0	0	2	1	14	18	33
			292	6	5	303
			1	4	3	8
0	0	0	0	9	7	16
1	0	10	0	119	72	191
			0	6	4	10
0	0	0	1	48	38	87
0	0	0	6	30	21	57
			4	104	152	260
0	0	0	2	171	189	362
			0	0	3	3
			0	0	0	0
0	0	0	0	0	0	0
			1	17	7	25
			0	3	1	4
			0	0	0	0
0	0	1				
0	0	0				

APPENDIX V

Size frequency

Mesidotea entomon

Telson Length, mm	Harrison Bay			Area Simpson Lagoon			Beaufort Sea		
	J	M	F	J	M	F	J	M	F
0–2	56			394			299		
2–4	24			117			0		
4–6	11			84			2		
6–8	11			65			19		
8–10					13	17		3	66
10–12					26	72		71	164
12–14					42	41		137	162
14–16		1	1		27	23		108	98
16–18					29	31		92	111
18–20		1	1		28	24		103	79
20–22		1	3		26	16		73	43
22–24			1		26	4		58	12
24–26			1		13			42	
26–28		1			14			37	
28–30		2			5			24	
30–32		4			10			35	
32–34		4			4			29	
34–36					2			6	
36–38								2	

[1] J=Junveniles; M=Males; F=Females

APPENDIX VI

Size frequency

Mysis oculata

Total Length, mm	Area		
	Harrison Bay	Simpson Lagoon	Beaufort Sea
4-6	6		
6-8	347	427	308
8-10	813	1161	772
10-12	32	130	65
12-14	49	97	202
14-16	302	927	725
16-18	347	943	492
18-20	103	158	114
20-22	38	77	23
22-24	5	9	3
24-26	1		
26-28		1	2
28-30		1	
35-36		1	
38-40			1

APPENDIX VII

Total length vs telson length

Mesidotea entomon

Category	Telson Length, mm	Total Length, mm
Juvenile	1	4, 3, 5, 4, 3
	2	8, 8, 7, 7, 6, 6
	3	11, 10
	4	12, 12
	5	14, 14
	6	16
	7	19, 19
	8	22, 22, 20
Female	9	24, 24
	10	26, 25, 26, 27
	11	29, 28, 30, 30, 30
	12	32, 32, 32, 32, 32
	13	36, 35, 35, 36, 34, 33, 36,
	14	41, 39, 39, 40, 39, 40
	15	43, 43, 42
	16	42, 42, 44, 44, 44, 44, 44, 44, 43, 44, 46
	17	50, 47, 47, 47, 47, 47, 47, 47, 49, 50
	18	47, 47, 51, 47, 47, 49, 49, 47, 49, 50
	19	49, 51, 50
	20	54, 56, 57
	21	55, 54, 55, 51
	22	61, 61
Male	12	35, 34
	13	35, 35
	14	40, 39, 40, 39, 40
	15	42, 42
	16	44, 44, 43, 44, 42
	17	46, 45, 47
	18	50
	19	53
	20	51, 51, 54, 53, 54
	22	65, 59, 59
	23	66, 61, 59
	24	60, 62, 60
	25	66, 64
	26	68
	27	77, 73, 69
	28	74
	29	78
	30	75, 75
	31	82
	32	78, 86, 80
	33	87, 82
	34	85, 87
	35	85

APPENDIX VIII

Measured formalin dry weight

Mesidotea entomon

Category	Telson Length, mm	Dry Weight, mg Specimen I	Specimen II	Specimen III
Juvenile	0-2	(30 specimens; average weight, 0.3)		
	2-4	(5 specimens; average weight, 0.6)		
	4-6	(6 specimens; average weight, 6.5)		
	6-8	33	26	12
Male	8-10	50	61	42
	10-12	62	75	74
	12-14	96	129	124
	14-16	141	161	130
	16-18	183	217	232
	18-20	263	343	261
	20-22	303	299	325
	22-24	606	643	456
	24-26	709	461	643
	26-28	780	809	811
	28-30	1022	789	675
	30-32	1328	994	1618
	32-34	1233	1588	1270
	34-36	1688	890	1623
	36-38	1811	1775	
Female	8-10	52	35	39
	10-12	82	65	78
	12-14	104	77	167
	14-16	117	226	257
	16-18	175	312	227
	18-20	324	260	427
	20-22	306	381	355
	22-24	438	339	430

APPENDIX IX

Measured formalin dry weight

Mysis oculata

Total Length, mm	Number	Average Dry Weight, mg
6-8	11	0.1
8-10	7	0.4
10-12	6	0.7
12-14	2	2.0
14-16	10	4.6
16-18	9	6.4
18-20	2	8.0
20-22	8	12.1
22-24	3	13.3
28-30	1	17.0
30-32	1	22.0
34-36	1	26.0
38-40	1	48.0